1967 Yearbook of Astronomy

Editor PATRICK MOORE

YEARBOOK OF ASTRONOMY 1967

EDITED BY
PATRICK MOORE

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Editorial

There has seemed to be no call for any major changes in the style or content of the *Yearbook*, though in this issue more technically-minded readers will be glad to see the inclusion of the review article about quasars written by Dr E. M. Lindsay.

Once again, most grateful thanks are due to Dr J. G. Porter. Without his help, production of the *Yearbook* would be well-nigh impossible.

PATRICK MOORE

The Planetarium,
Armagh.

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YEARBOOKS

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DALL, H. E. *Eyepieces – a Practical Assessment:* 1963.
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PART ONE

Events of 1967

Monthly Charts and Astronomical Phenomena

Notes on the Star Charts

The stars, together with the Sun, Moon and planets, seem to be set on the surface of the celestial sphere, which appears to rotate about the Earth from east to west. Since it is impossible to represent a curved surface accurately on a plane, any kind of star map is bound to contain some form of distortion. But it is well known that the eye can endure some kinds of distortion better than others, and it is particularly true that the eye is most sensitive to deviations from the vertical and horizontal. For this reason the star charts given in this volume on pages 6 to 29 have been designed to give a true representation of vertical and horizontal lines, whatever may be the resulting distortion in the shape of a constellation figure. It will be found that the amount of distortion is, in general, quite small, and is only obvious in the case of large constellations such as Leo and Pegasus, when these appear at the top of the charts, and so are drawn out sideways.

The charts show all stars down to the fourth magnitude, together with a number of fainter stars which are necessary to define the shape of a constellation. There is no standard system for representing the outlines of the constellations, and triangles and other simple figures have been used to give outlines which are easy to follow with the naked eye. The names of the constellations are given, together with the proper names of the brighter stars. The apparent magnitudes of the stars are indicated roughly by using four different sizes of dots, the larger dots representing the bright stars.

There are four such charts at each opening, and these give a complete coverage of the sky up to an altitude of $62\frac{1}{2}$ degrees; there are twelve such sets to cover the entire year. The upper two charts show the southern sky, south being at the centre; the coverage is 200 degrees in azimuth, from a little north of east

(top left) to a little north of west (top right). The two lower charts show the northern sky, from a little south of west (lower left) to a little south of east (lower right). There is thus an overlap east and west.

The charts have been drawn for a latitude of 52 degrees, but may be taken without appreciable error to apply to all parts of the British Isles. They will also be equally suitable for any other part of the world having a north latitude of about 52 degrees – e.g. parts of Europe and Asia, and Canada. In such cases the times given must be taken as local time, and not G.M.T., which applies only to the British Isles.

Because the sidereal day is shorter than the solar day, the stars appear to rise and set about four minutes earlier each day, which amounts to two hours in a month. Hence the twelve sets of charts are sufficient to give the appearance of the sky throughout the day at intervals of two hours, or at the same time of night at monthly intervals throughout the year. The actual range of dates and times when the stars on the charts are visible is indicated at the top of each page. This information is summarized in the following table, which gives the number of the star chart to be used for any given month and time.

G.M.T.	16^h	18^h	20^h	22^h	0^h	2^h	4^h	6^h
January	10	11	12	1	2	3	4	5
February		12	1	2	3	4	5	6
March			2	3	4	5	6	
April			3	4	5	6		
May			4	5	6	7		
June			5	6	7			
July			6	7	8	9		
August			7	8	9	10	11	
September		7	8	9	10	11	12	
October		8	9	10	11	12	1	
November	8	9	10	11	12	1	2	3
December	9	10	11	12	1	2	3	4

The charts are drawn to scale, and estimates of altitude and azimuth may be made from them. These values will necessarily be mere approximations, since no observer will be exactly on the meridian of Greenwich at 52 degrees latitude, but they will generally serve for the identification of stars and planets. The horizontal measurements, marked at every ten degrees, give the azimuths (or true bearings) measured from the north round through east (90 degrees), south (180 degrees), and west (270 degrees). The vertical measurements, similarly marked, give the altitudes of the stars up to $62\frac{1}{2}$ degrees.

The ecliptic is drawn as a broken line on which the longitude is marked at every ten degrees; the positions of the planets at any time are then easily found by reference to the table immediately following the star charts on page 32.

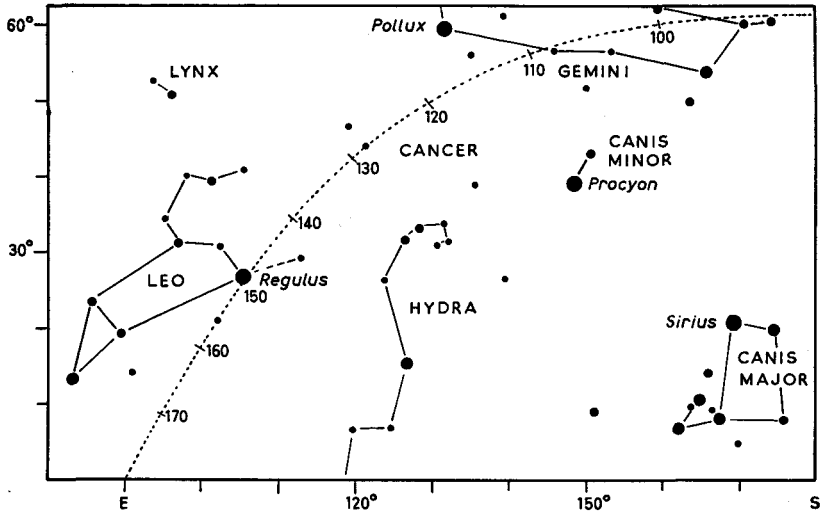
There is a curious illusion that stars at an altitude of 60 degrees or more are actually overhead, and the beginner may often feel that he is leaning over backwards in trying to see them. These high-altitude stars, being nearer the pole, move more slowly across the sky, and a different kind of map may therefore be used. These overhead stars are given separately on pages 30 and 31, the entire year being covered at one opening. Each of the four maps shows the overhead stars at times which correspond to those of three of the main star charts. The position of the zenith in latitude 52 degrees is indicated by a cross, and this cross also marks the centre of a circle which is 35 degrees from the zenith, and which therefore indicates an altitude of 55 degrees; there is thus a small overlap with the main charts.

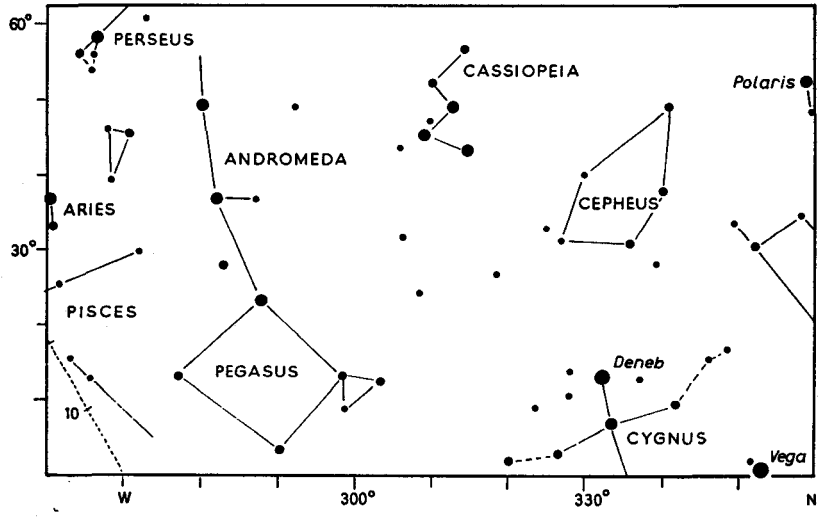
The broken line leading from north to south is numbered to indicate the corresponding main chart. Thus on page 30 the N-S line numbered 6 is to be regarded as an extension of the S line of chart 6 on pages 16 and 17, and at the top of these pages are given dates and times which are appropriate.

The scale is the same on all the charts (approximately 25 degrees to the inch), but the overhead stars are plotted as a true map on a conical projection, and are not simple graphs like the main charts.

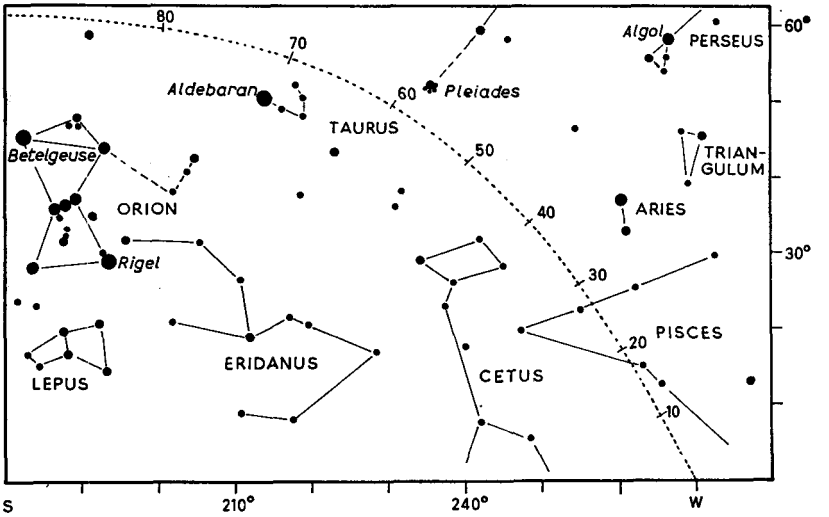
1L

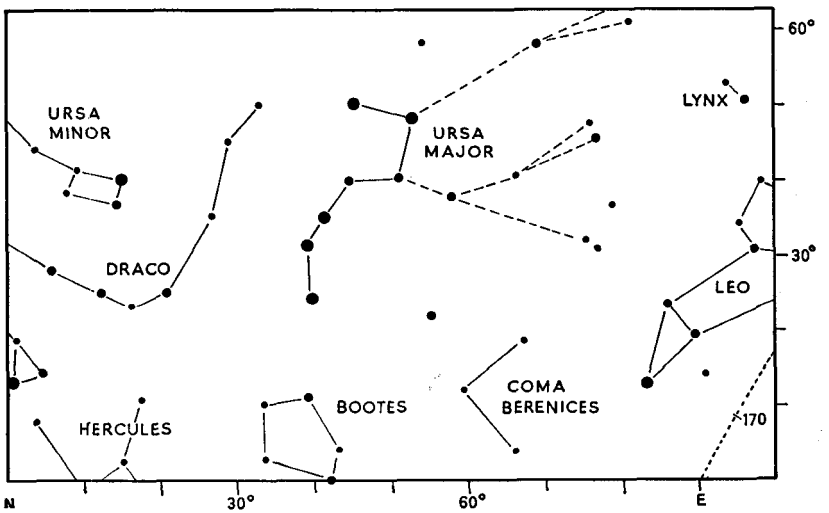
October 6 at	5^h	October 21 at	4^h
November 6 at	3^h	November 21 at	2^h
December 6 at	1^h	December 21 at	midnight
January 6 at	23^h	January 21 at	22^h
February 6 at	21^h	February 21 at	20^h





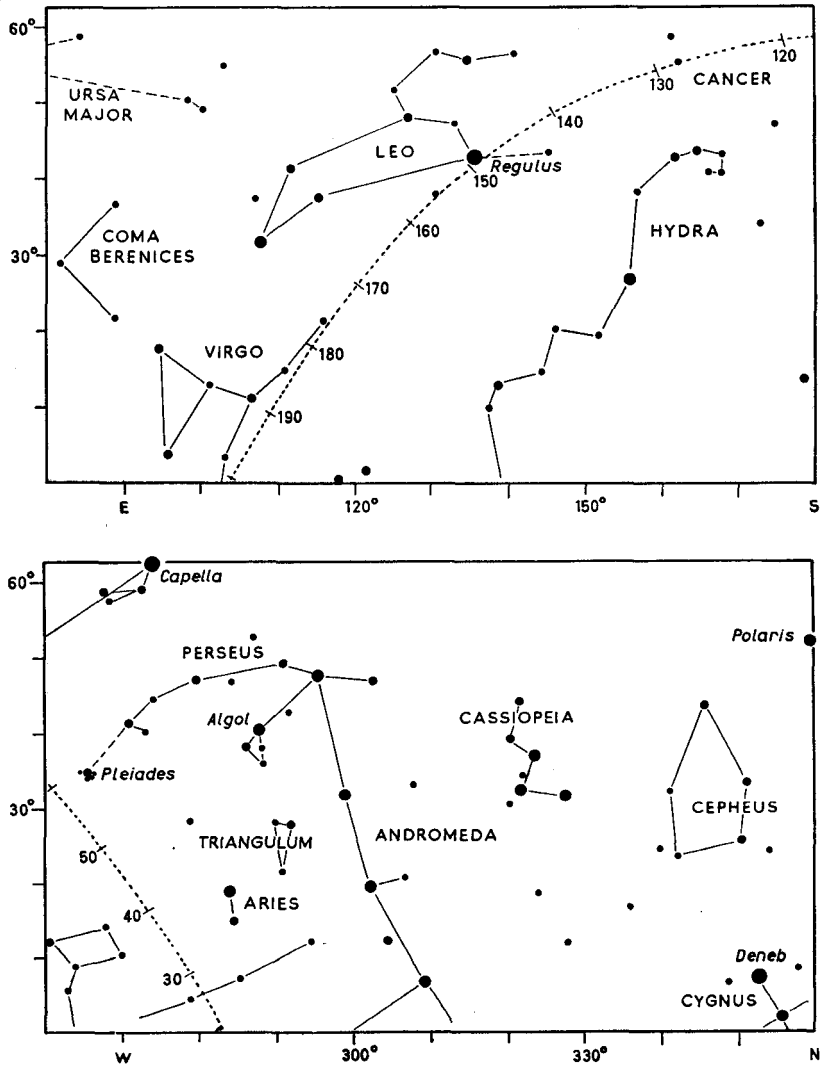
October 6 at 5h	October 21 at 4h	**1R**
November 6 at 3h	November 21 at 2h	
December 6 at 1h	December 21 at midnight	
January 6 at 23h	January 21 at 22h	
February 6 at 21h	February 21 at 20h	





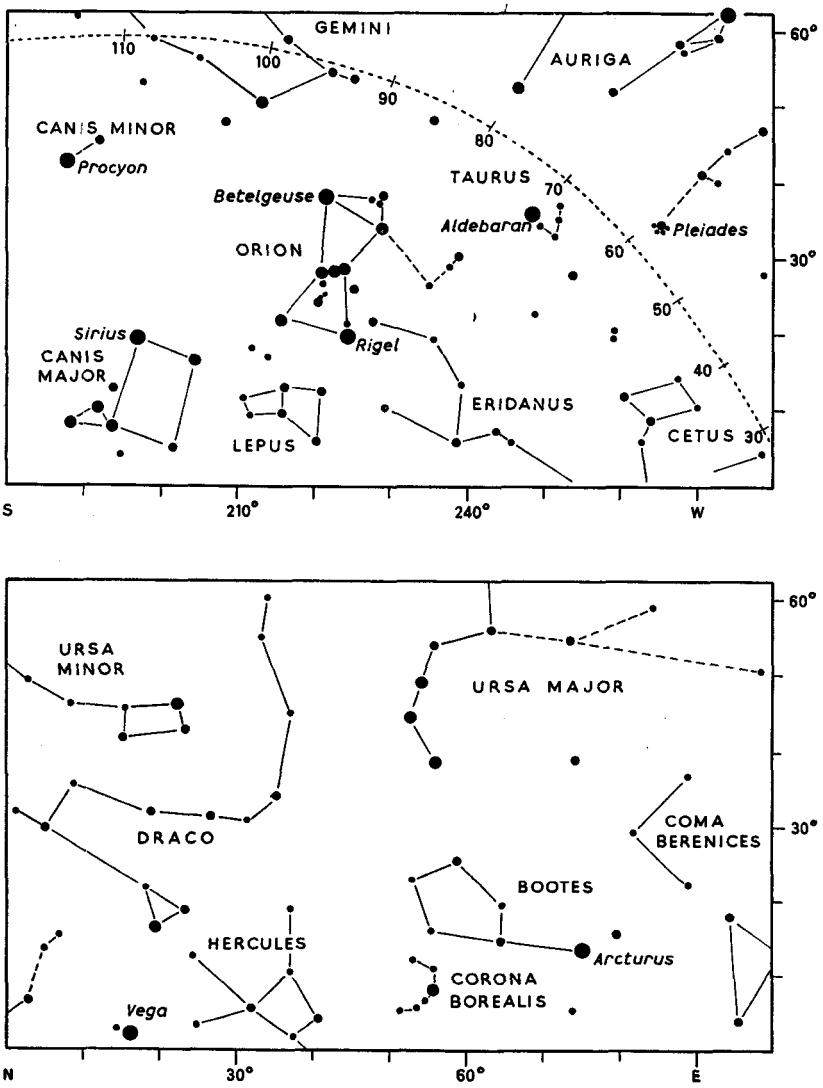
2L

November 6 at	5^h	November 21 at	4^h
December 6 at	3^h	December 21 at	2^h
January 6 at	1^h	January 21 at	midnight
February 6 at	23^h	February 21 at	22^h
March 6 at	21^h	March 21 at	20^h



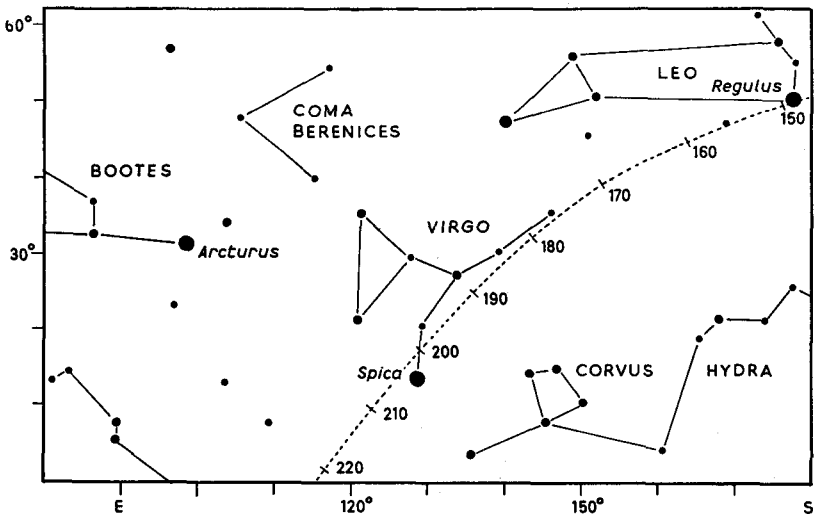
November 6 at 5h	November 21 at 4h
December 6 at 3h	December 21 at 2h
January 6 at 1h	January 21 at midnight
February 6 at 23h	February 21 at 22h
March 6 at 21h	March 21 at 20h

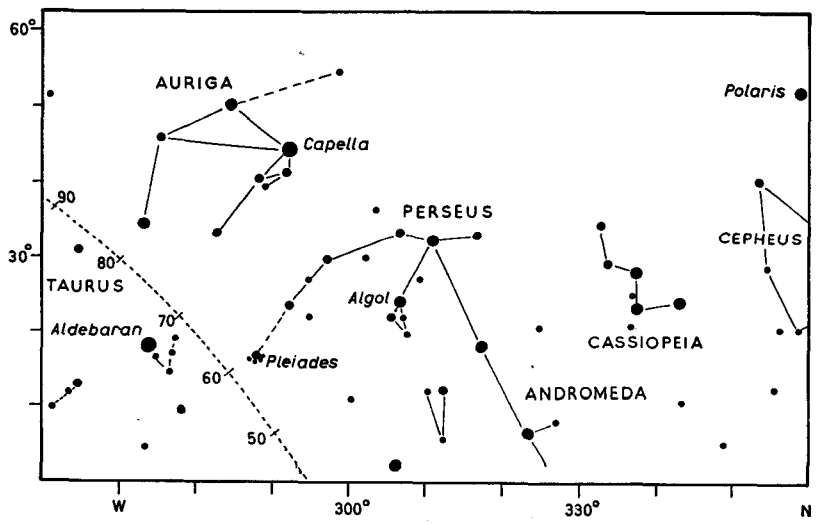
2R



3L

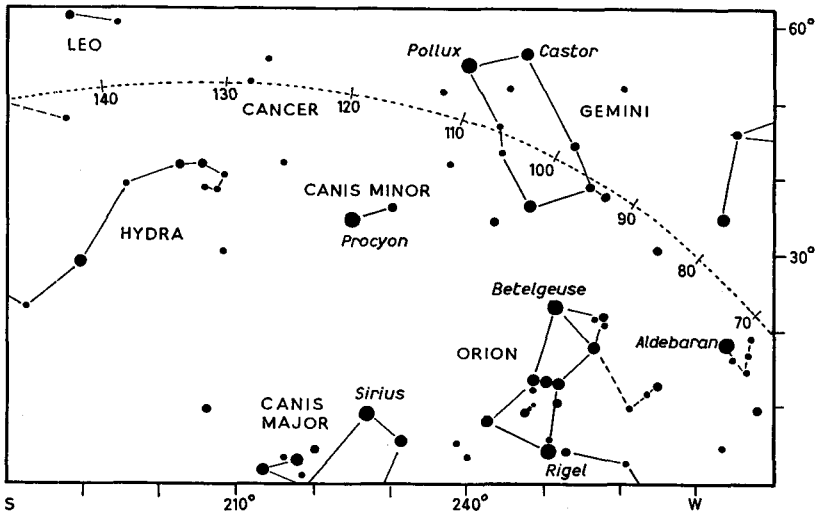
December 6 at 5h	December 21 at 4h
January 6 at 3h	January 21 at 2h
February 6 at 1h	February 21 at midnight
March 6 at 23h	March 21 at 22h
April 6 at 21h	April 21 at 20h

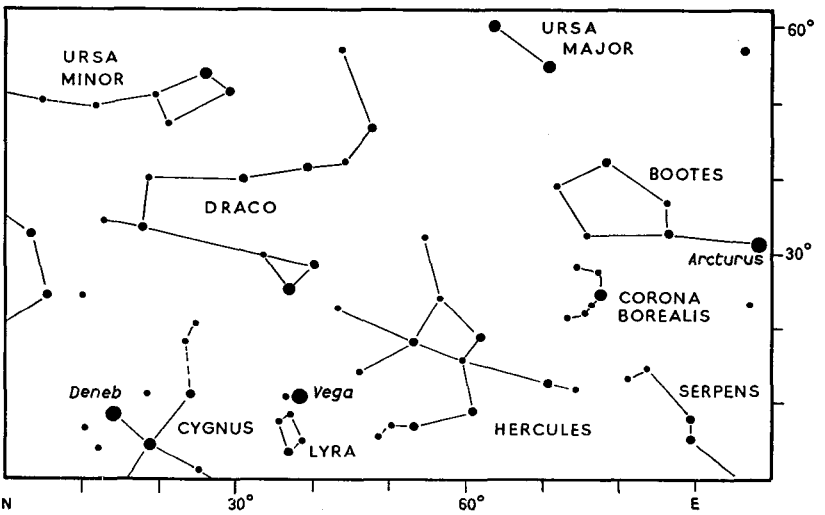




December 6 at 5h	December 21 at 4h
January 6 at 3h	January 21 at 2h
February 6 at 1h	February 21 at midnight
March 6 at 23h	March 21 at 22h
April 6 at 21h	April 21 at 20h

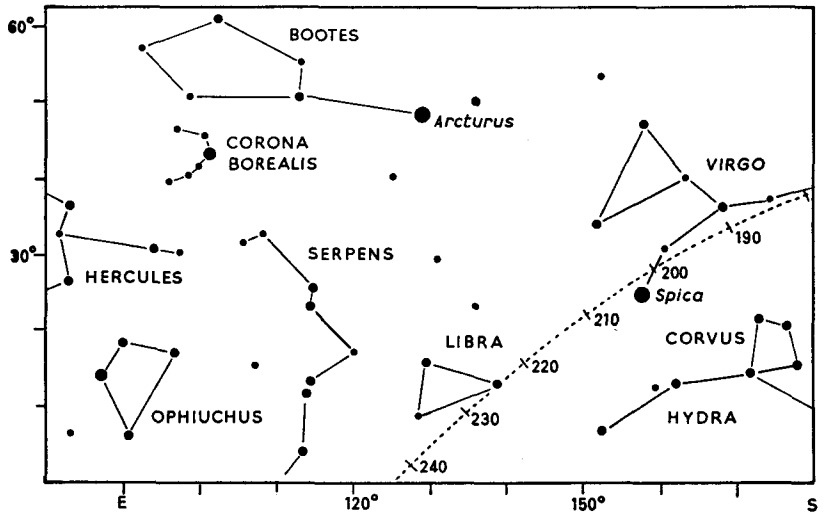
3R

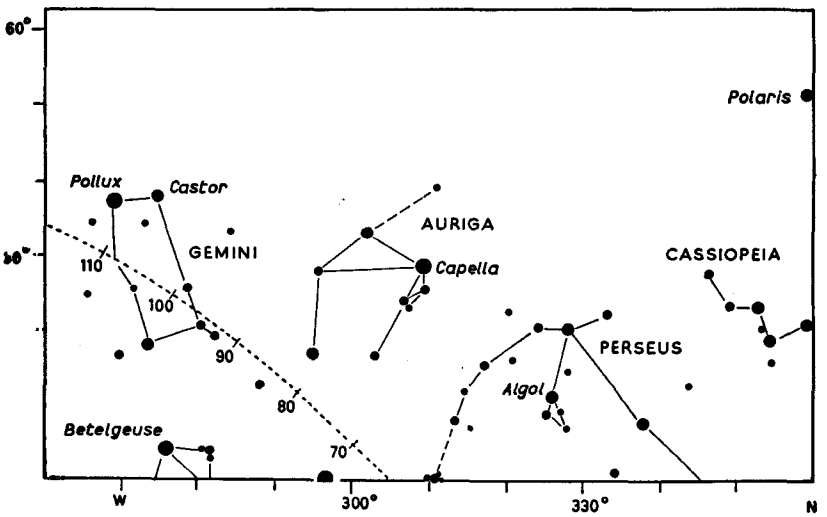




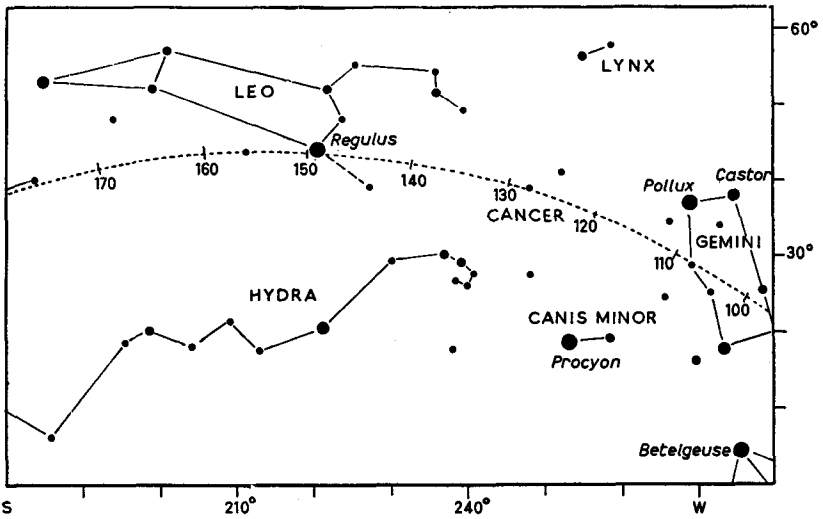
4L

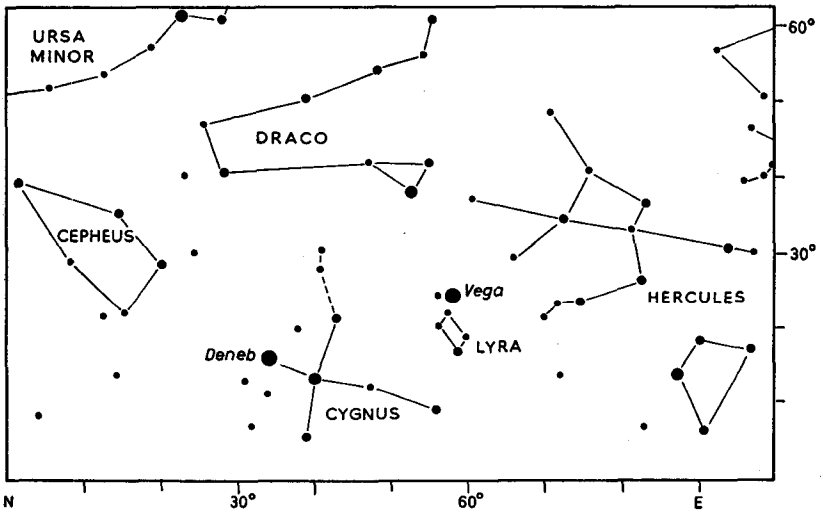
January 6 at	5^h	January 21 at	4^h
February 6 at	3^h	February 21 at	2^h
March 6 at	1^h	March 21 at	midnight
April 6 at	23^h	April 21 at	22^h
May 6 at	21^h	May 21 at	20^h





January 6 at 5h	January 21 at 4h	**4R**
February 6 at 3h	February 21 at 2h	
March 6 at 1h	March 21 at midnight	
April 6 at 23h	April 21 at 22h	
May 6 at 21h	May 21 at 20h	





5L

January 6 at 7h	January 21 at 6h
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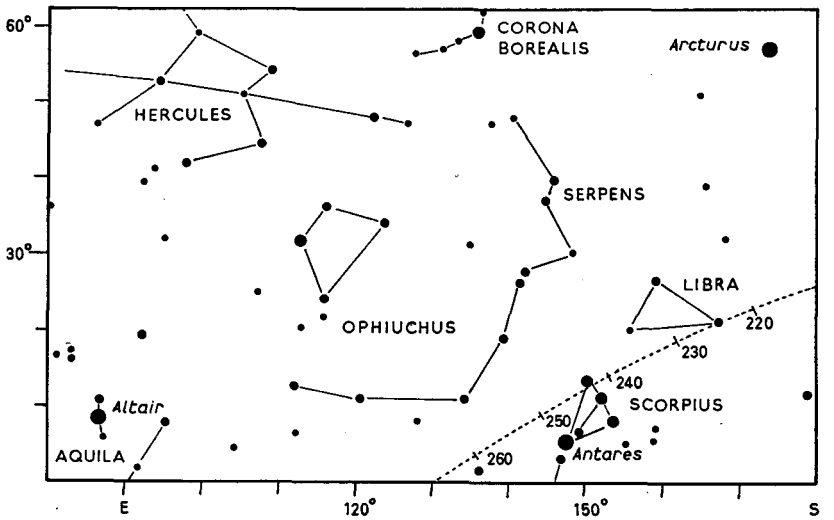
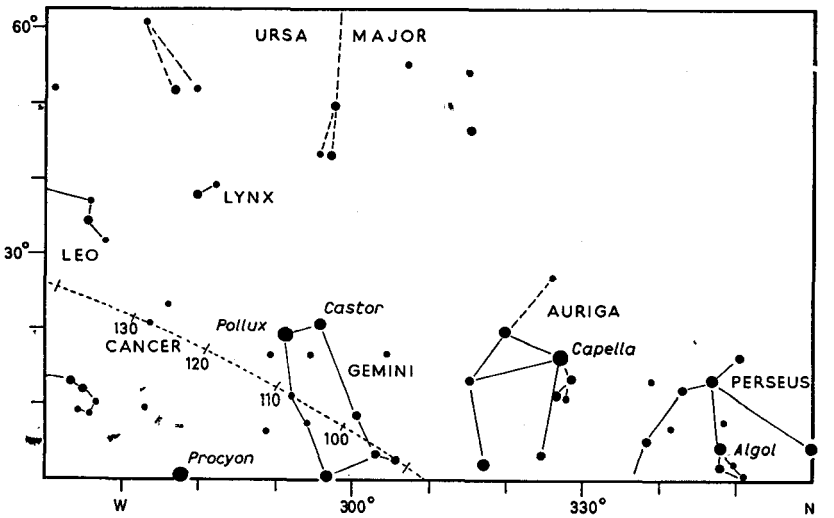
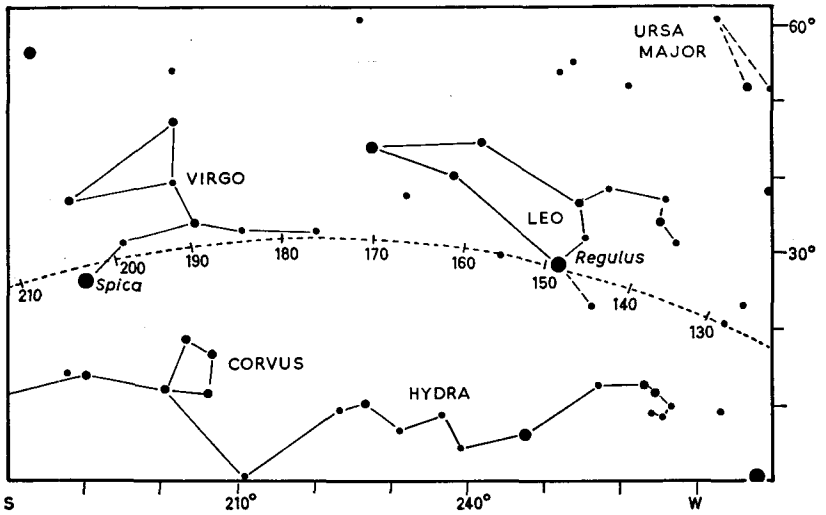
May 6 at 23h	May 21 at 22h

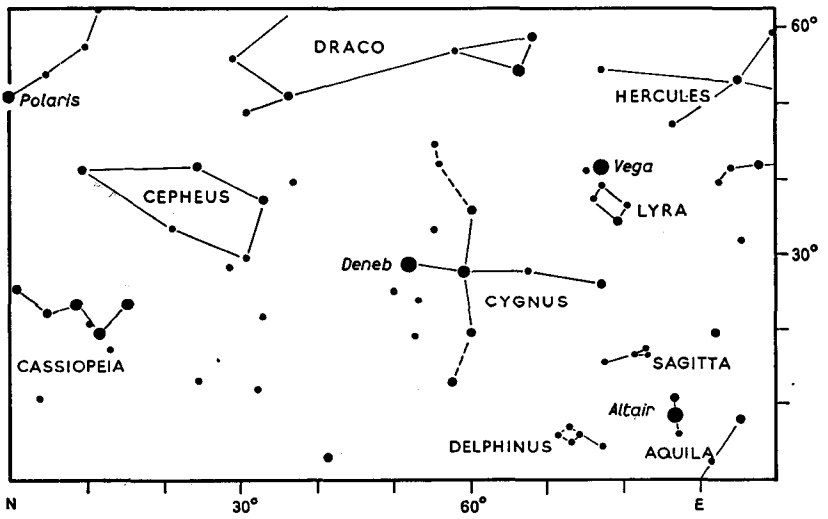




January 6 at	7^h	January 21 at	6^h
February 6 at	5^h	February 21 at	4^h
March 6 at	3^h	March 21 at	2^h
April 6 at	1^h	April 21 at	midnight
May 6 at	23^h	May 21 at	22^h

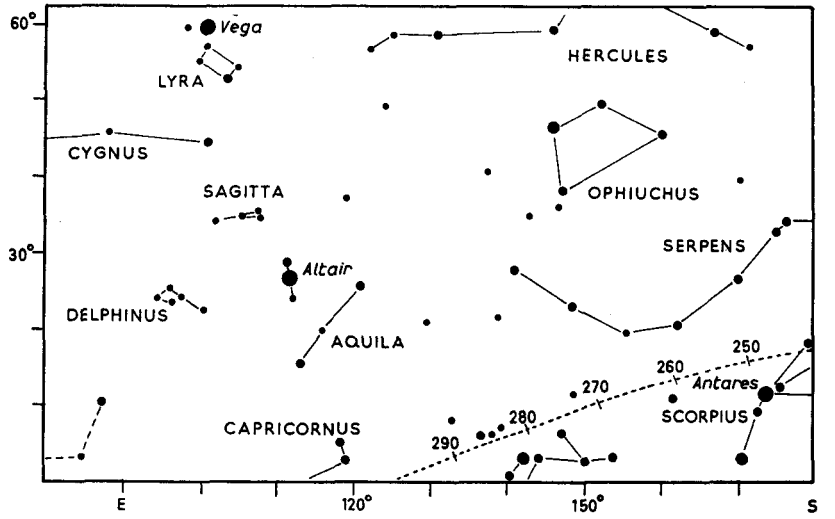
5R

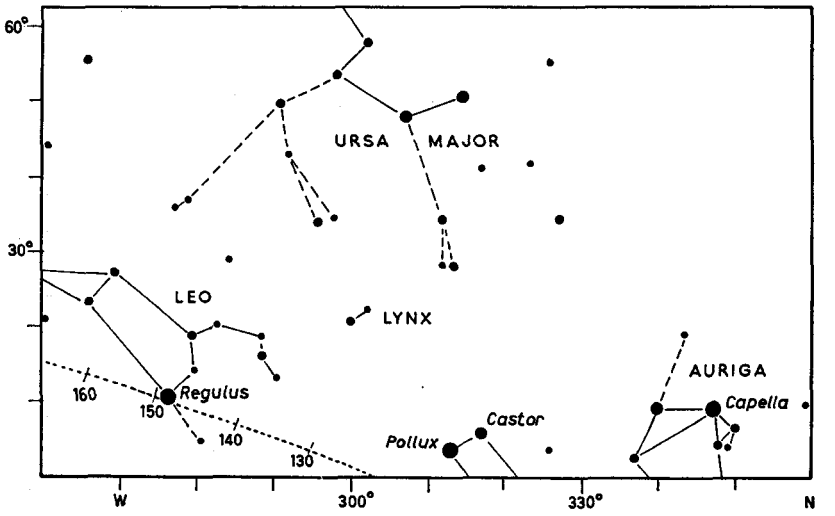




6L

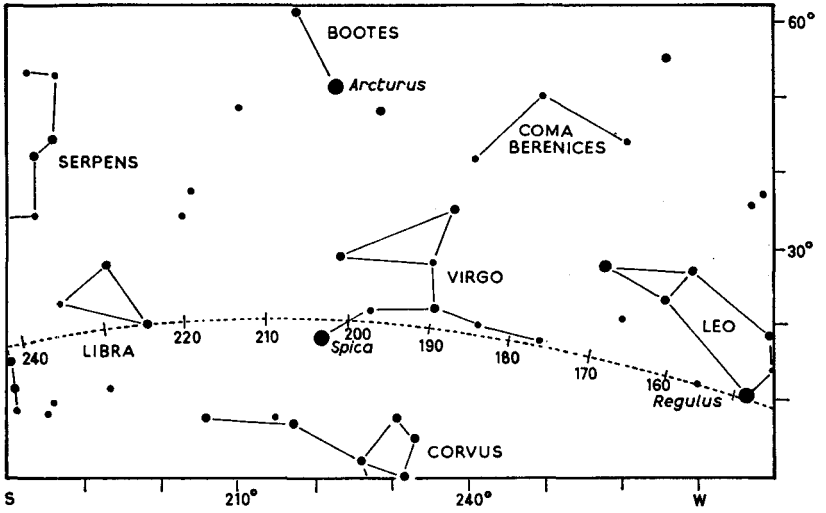
March 6 at 5h	March 21 at 4h
April 6 at 3h	April 21 at 2h
May 6 at 1h	May 21 at midnight
June 6 at 23h	June 21 at 22h
July 6 at 21h	July 21 at 20h

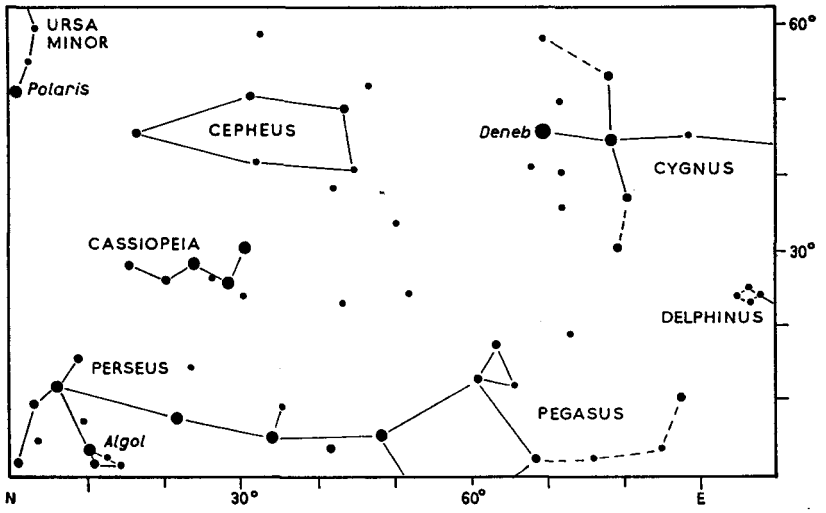




March 6 at	5^h	March 21 at	4^h
April 6 at	3^h	April 21 at	2^h
May 6 at	1^h	May 21 at	midnight
June 6 at	23^h	June 21 at	22^h
July 6 at	21^h	July 21 at	20^h

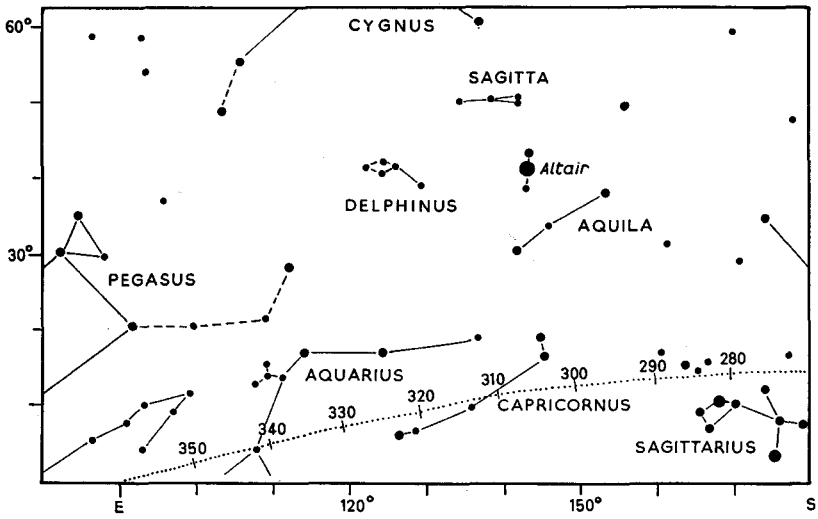
6R

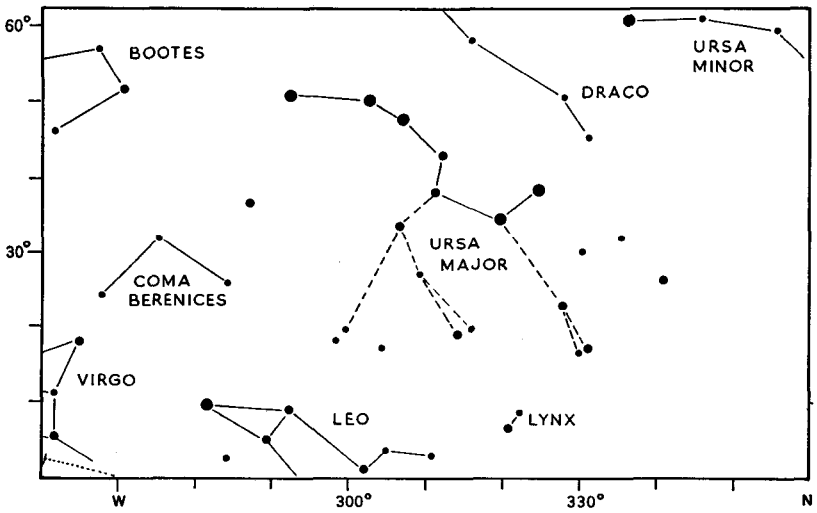




7L

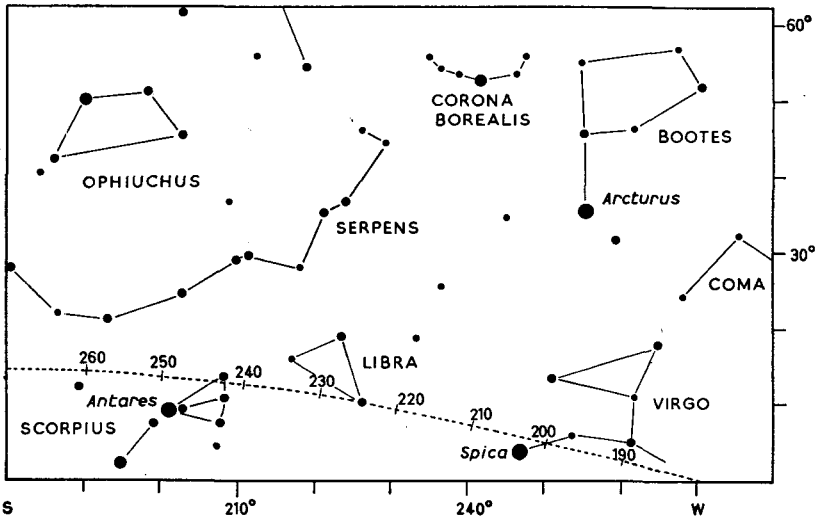
May 6 at 3h	May 21 at 2h
June 6 at 1h	June 21 at midnight
July 6 at 23h	July 21 at 22h
August 6 at 21h	August 21 at 20h
September 6 at 19h	September 21 at 18h

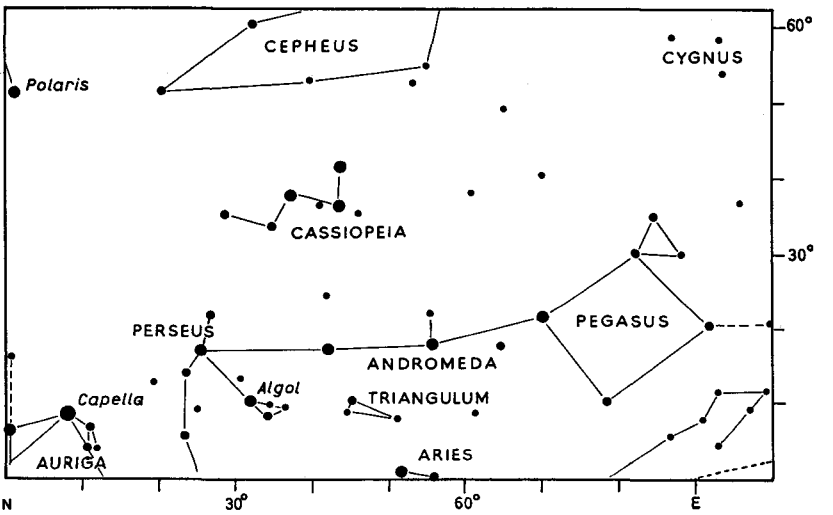




May 6 at 3h	May 21 at 2h
June 6 at 1h	June 21 at midnight
July 6 at 23h	July 21 at 22h
August 6 at 21h	August 21 at 20h
September 6 at 19h	September 21 at 18h

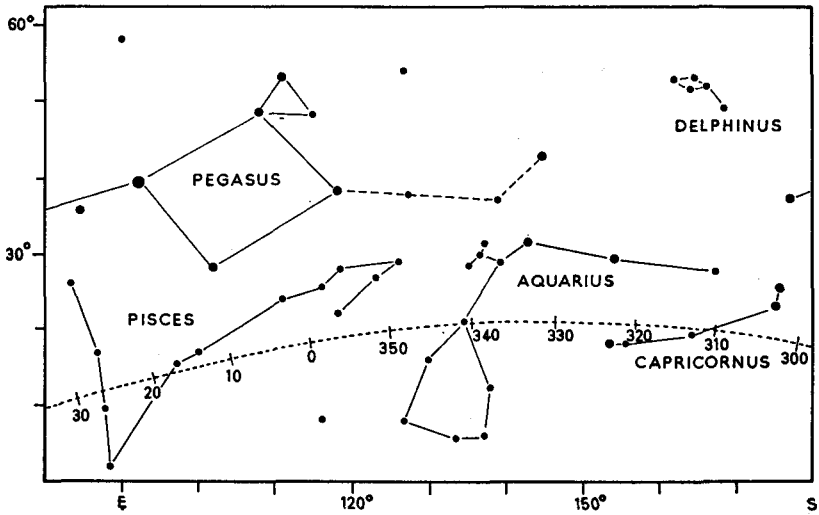
7R

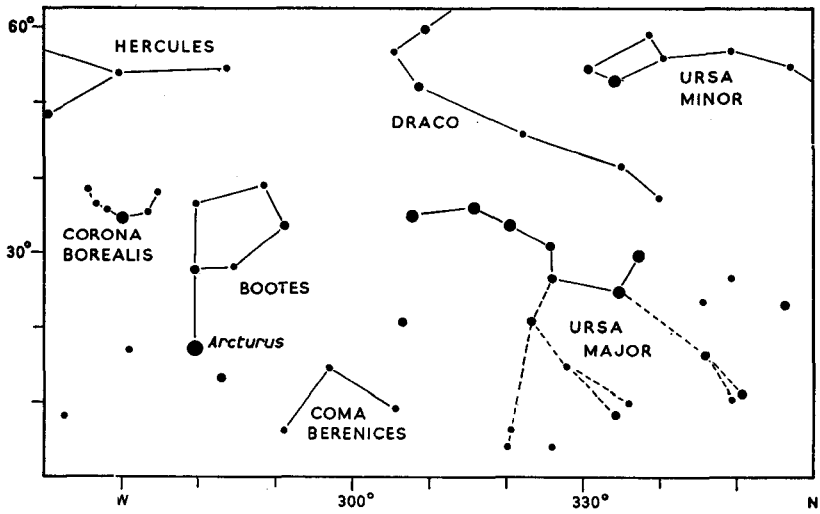




8L

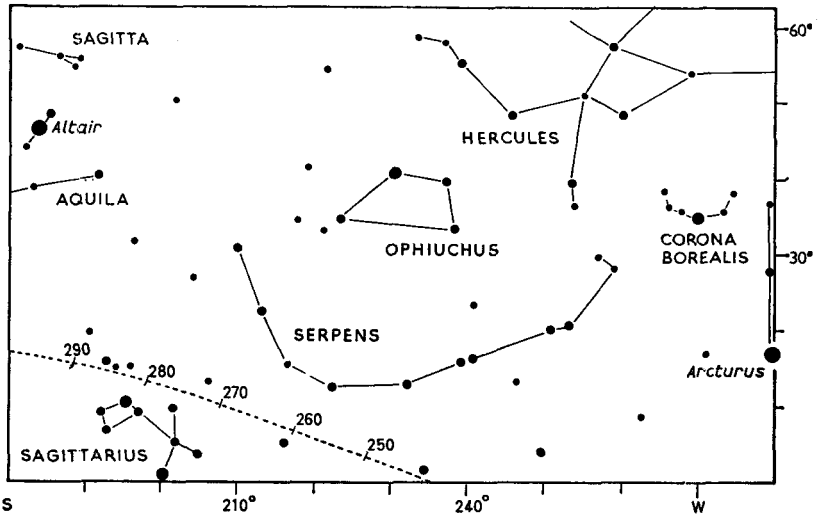
July 6 at 1h	July 21 at midnight
August 6 at 23h	August 21 at 22h
September 6 at 21h	September 21 at 20h
October 6 at 19h	October 21 at 18h
November 6 at 17h	November 21 at 16h

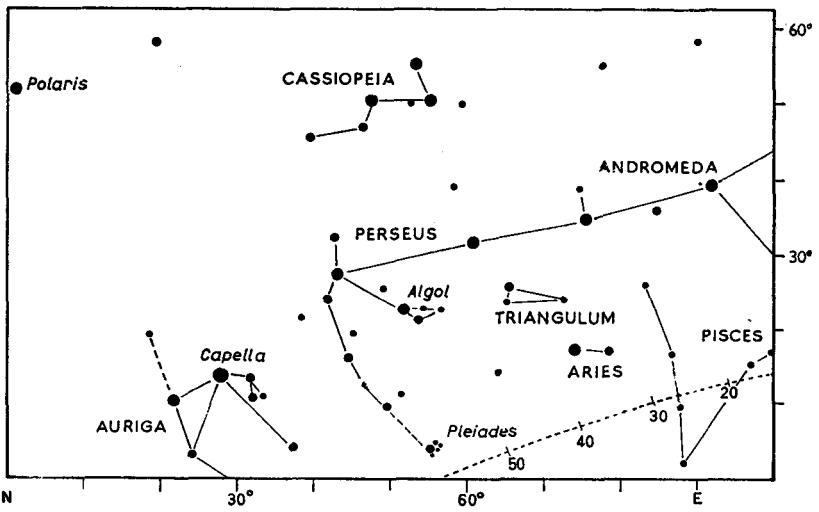




July 6 at 1h	July 21 at midnight
August 6 at 23h	August 21 at 22h
September 6 at 21h	September 21 at 20h
October 6 at 19h	October 21 at 18h
November 6 at 17h	November 21 at 16h

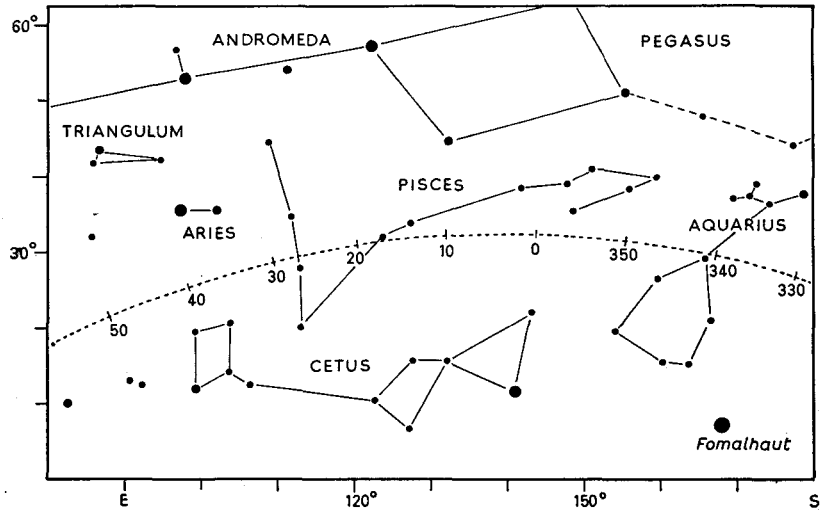
8R

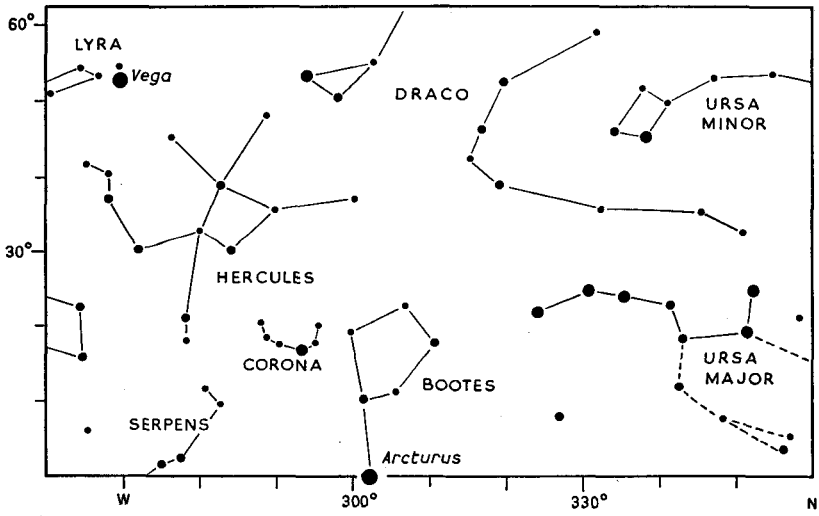




9L

August 6 at 1h	August 21 at midnight
September 6 at 23h	September 21 at 22h
October 6 at 21h	October 21 at 20h
November 6 at 19h	November 21 at 18h
December 6 at 17h	December 21 at 16h





August 6 at 1h	August 21 at midnight	**9R**
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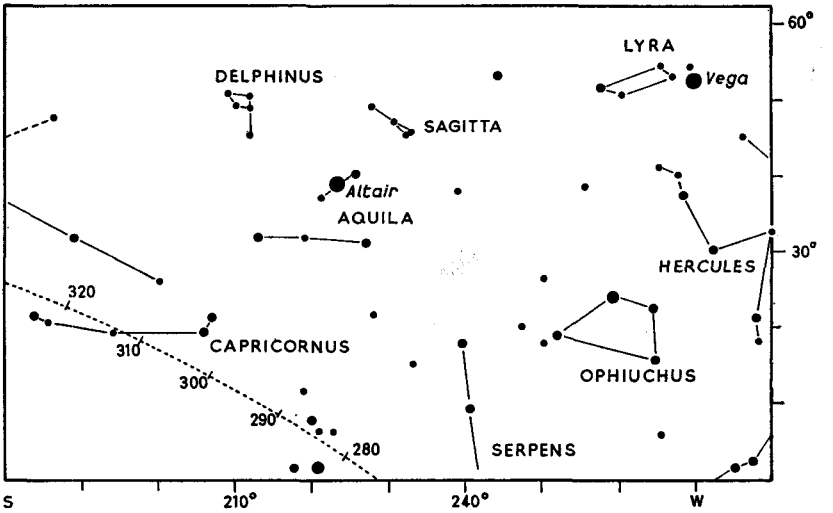
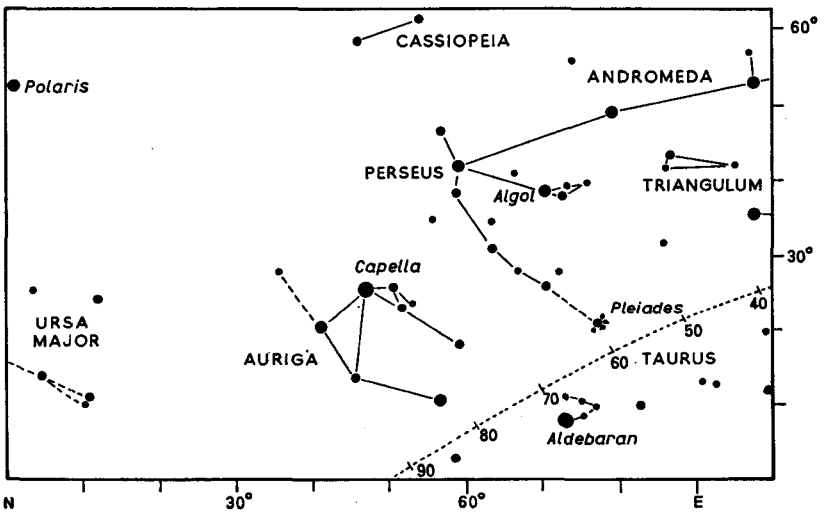
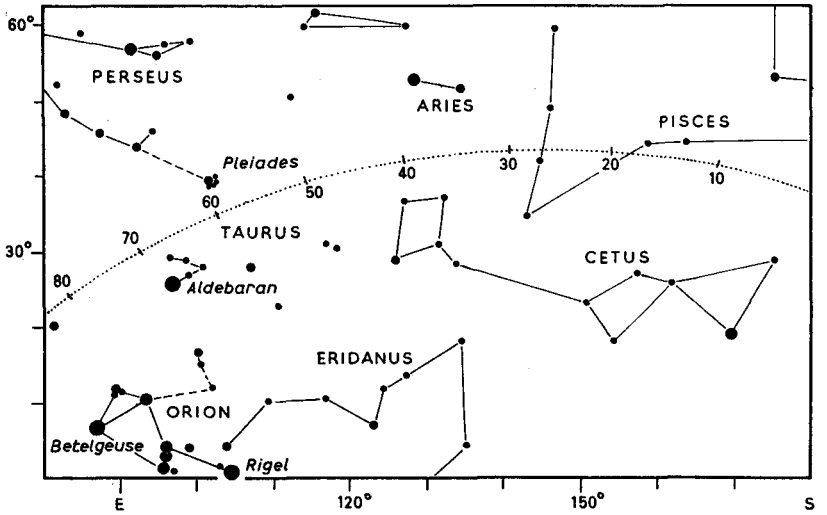
October 6 at 21h	October 21 at 20h	
November 6 at 19h	November 21 at 18h	
December 6 at 17h	December 21 at 16h	

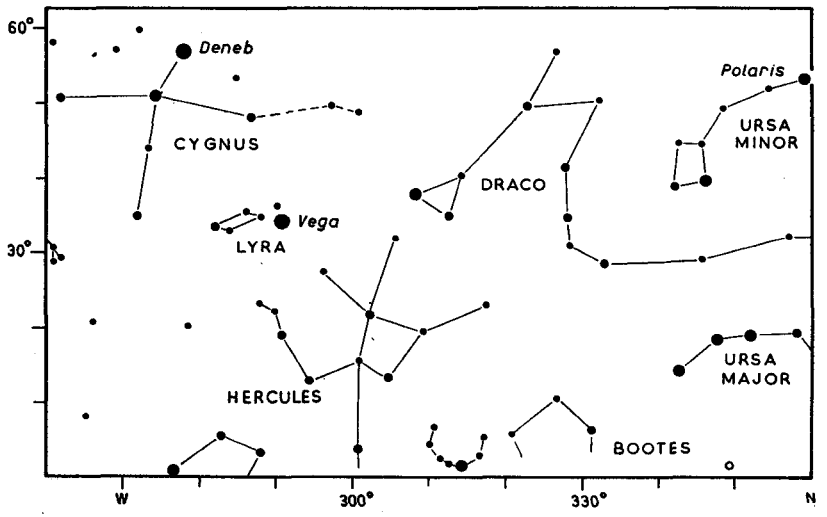




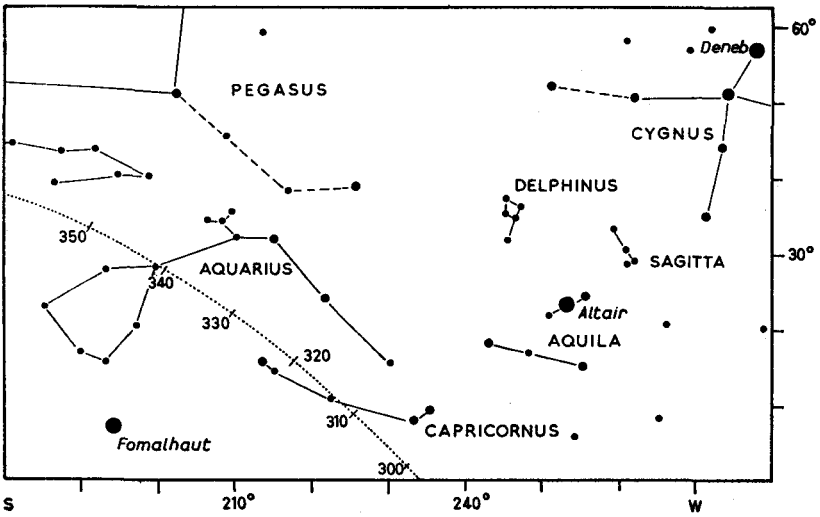
10L

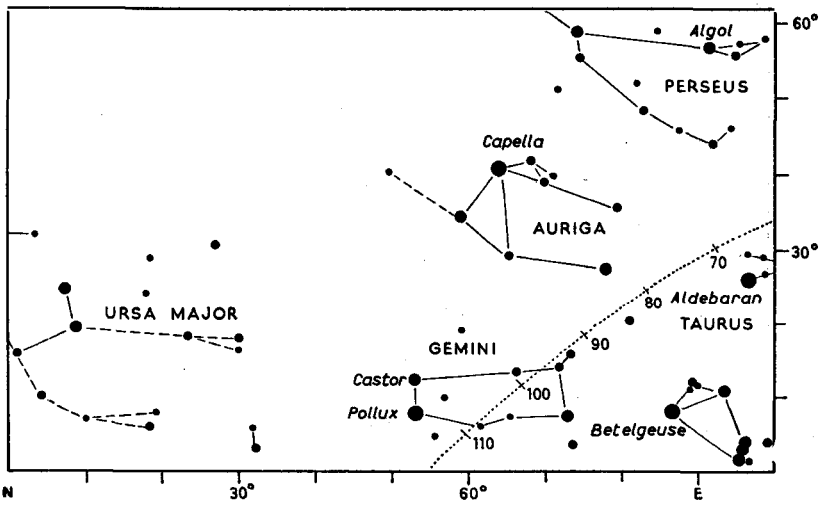
August 6 at 3h	August 21 at 2h
September 6 at 1h	September 21 at midnight
October 6 at 23h	October 21 at 22h
November 6 at 21h	November 21 at 20h
December 6 at 19h	December 21 at 18h





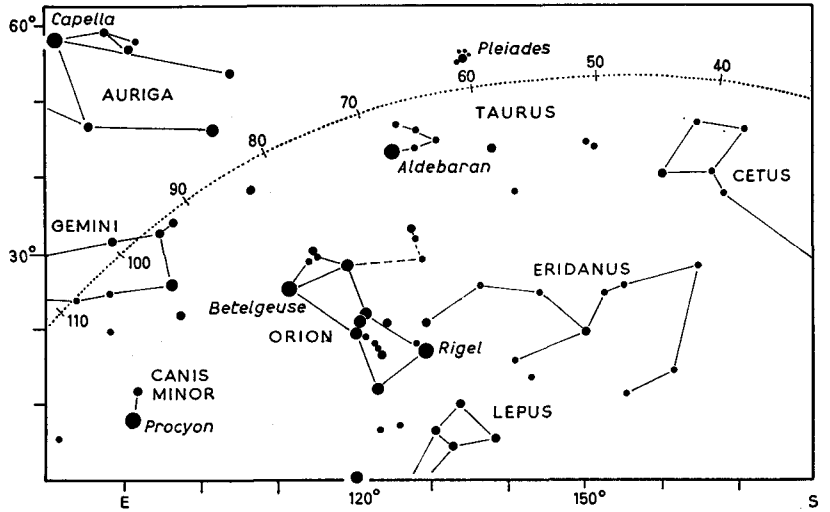
August 6 at 3h	August 21 at 2h	**10R**
September 6 at 1h	September 21 at midnight	
October 6 at 23h	October 21 at 22h	
November 6 at 21h	November 21 at 20h	
December 6 at 19h	December 21 at 18h	

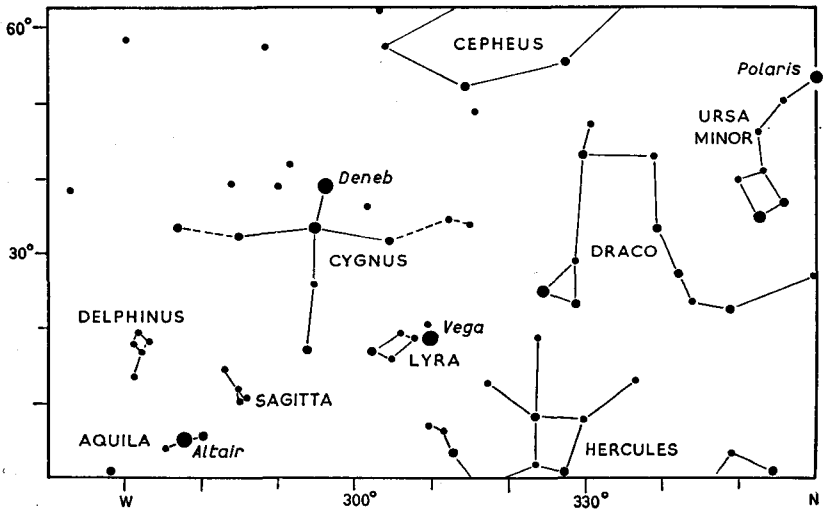




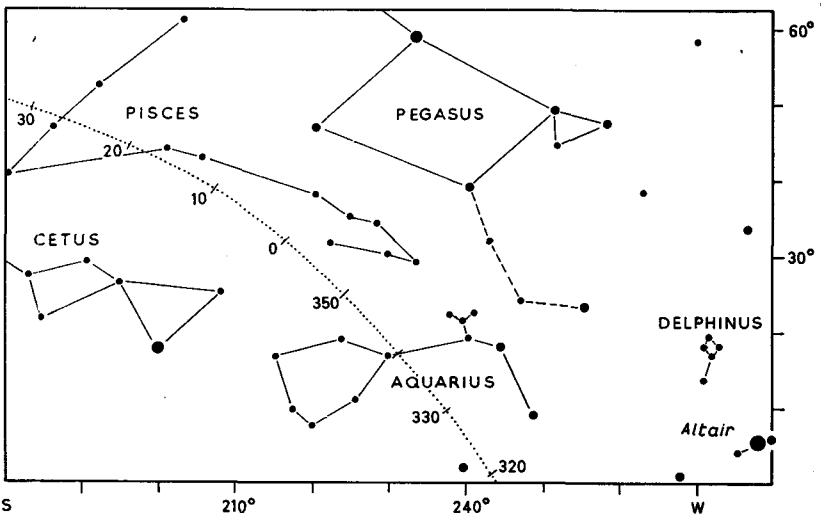
11L

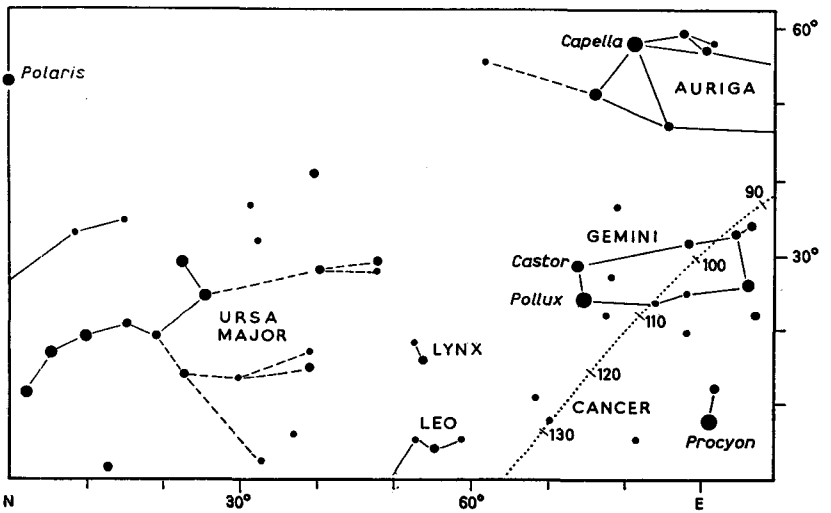
September 6 at 3h	September 21 at 2h
October 6 at 1h	October 21 at midnight
November 6 at 23h	November 21 at 22h
December 6 at 21h	December 21 at 20h
January 6 at 19h	January 21 at 18h





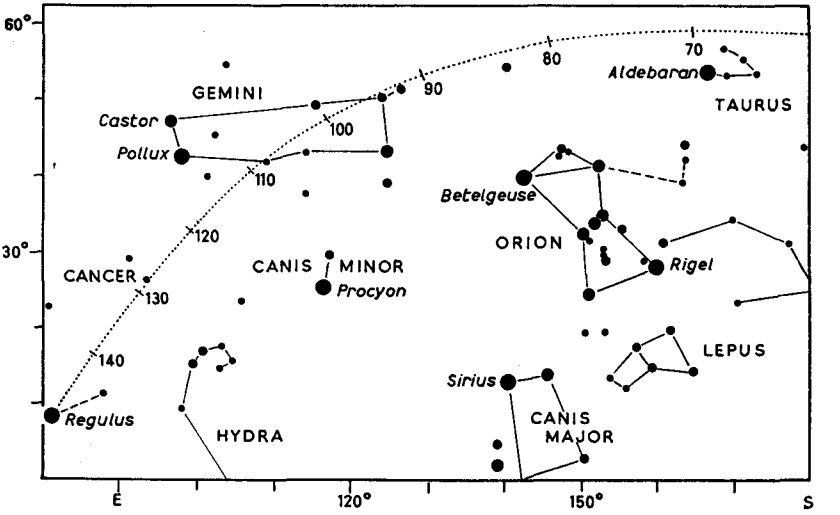
September 6 at 3h	September 21 at 2h	**11R**
October 6 at 1h	October 21 at midnight	
November 6 at 23h	November 21 at 22h	
December 6 at 21h	December 21 at 20h	
January 6 at 19h	January 21 at 18h	

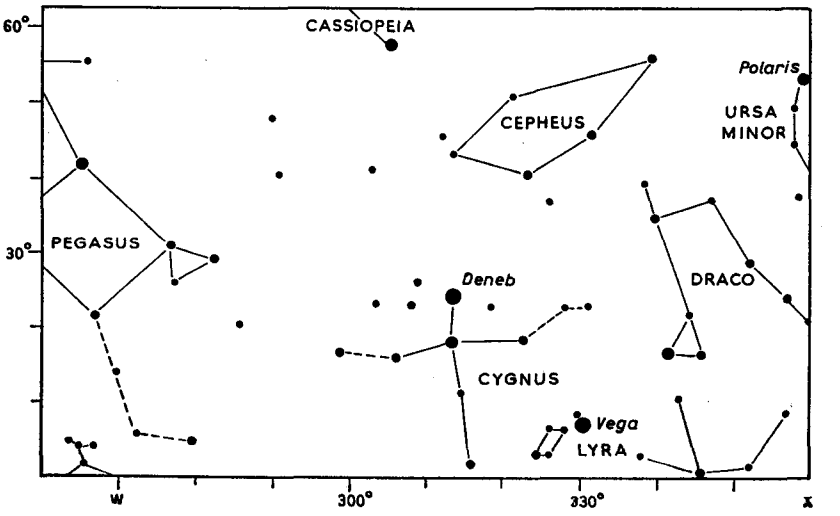




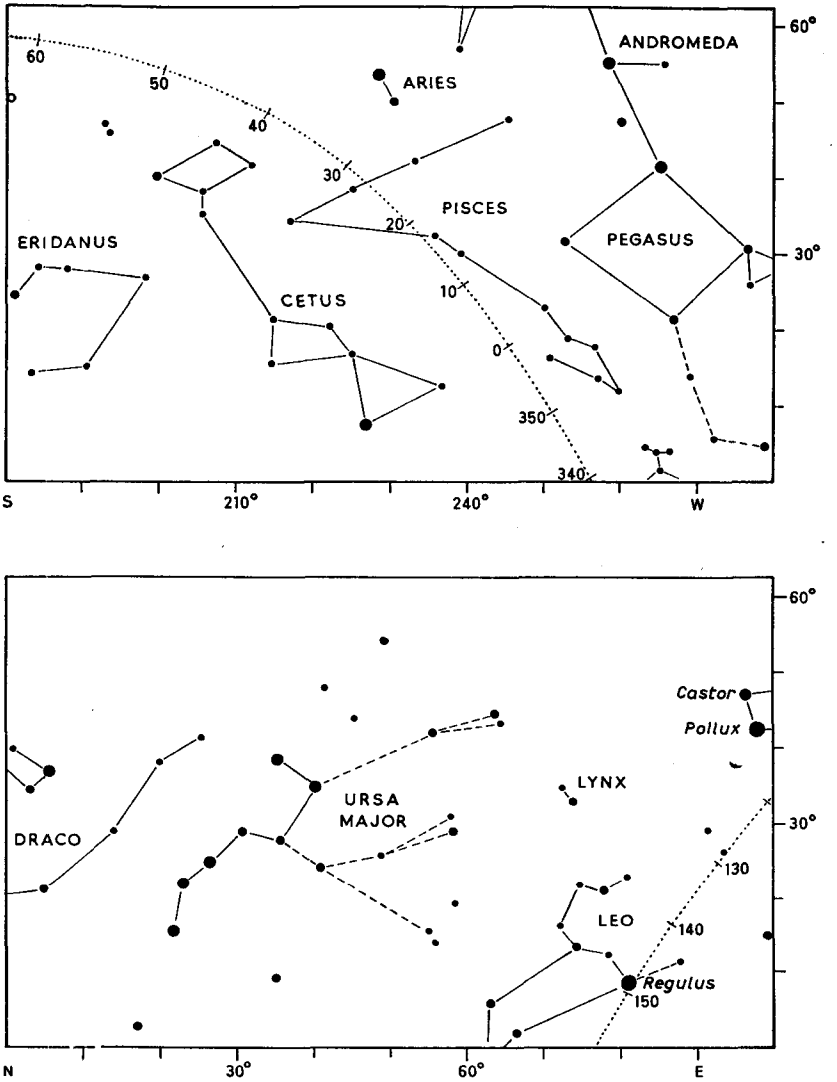
12L

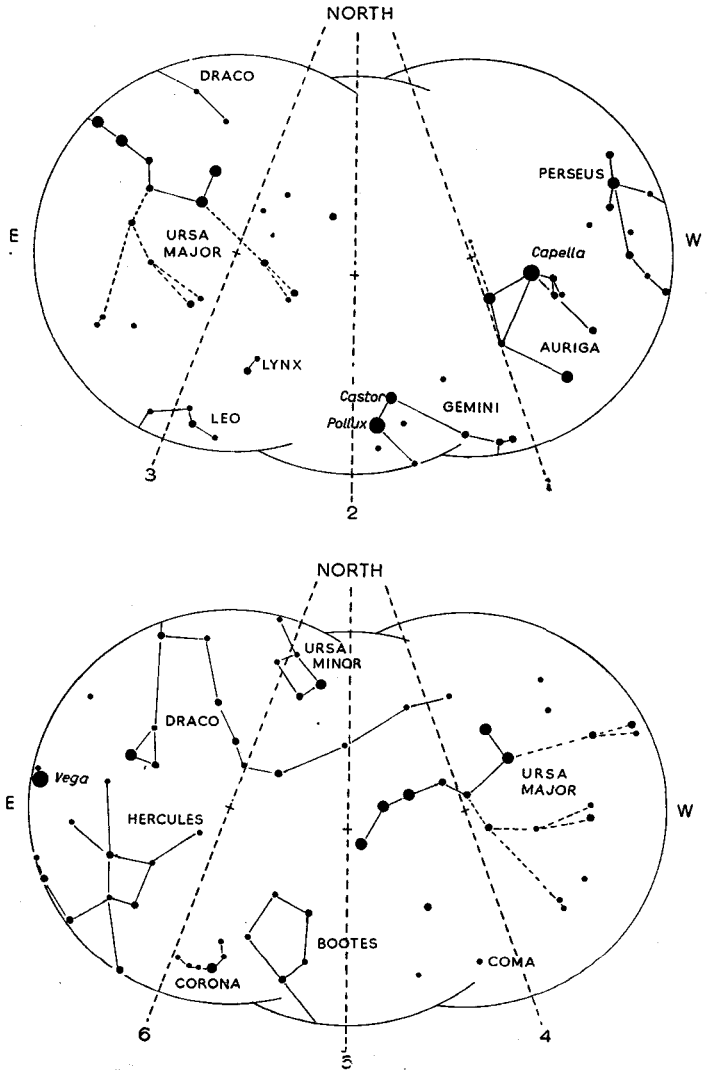
October 6 at 3h	October 21 at 2h
November 6 at 1h	November 21 at midnight
December 6 at 23h	December 21 at 22h
January 6 at 21h	January 21 at 20h
February 6 at 19h	February 21 at 18h



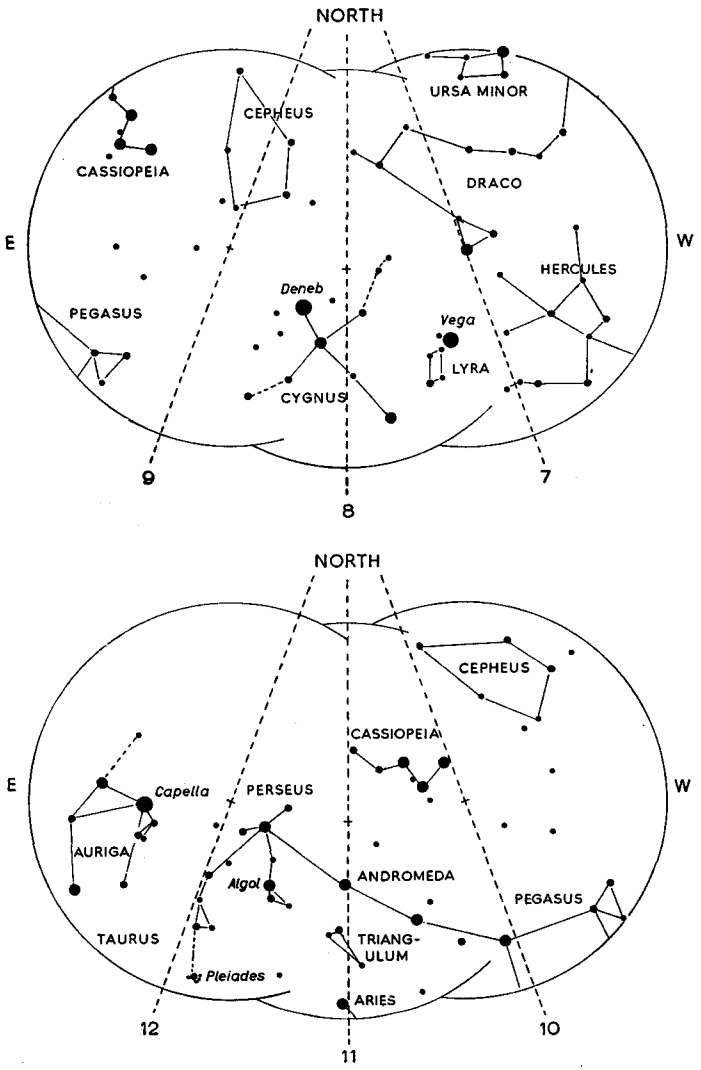


October 6 at 3h	October 21 at 2h	**12R**
November 6 at 1h	November 21 at midnight	
December 6 at 23h	December 21 at 22h	
January 6 at 21h	January 21 at 20h	
February 6 at 19h	February 21 at 18h	





Overhead stars



Overhead stars

The Planets in 1967

DATE		*Venus*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
January	6	299°	197°	121°	355°	175°	234°
	21	318°	204°	119°	356°	175°	234°
February	6	338°	209°	117°	358°	174°	235°
	21	357°	213°	116°	0°	174°	235°
March	6	13°	214°	115°	1°	173°	235°
	21	31°	213°	115°	3°	172°	235°
April	6	50°	209°	115°	5°	172°	234°
	21	67°	203°	116°	7°	171°	234°
May	6	85°	198°	118°	9°	171°	234°
	21	102°	193°	120°	10°	171°	233°
June	6	120°	196°	122°	11°	171°	233°
	21	135°	199°	125°	12°	171°	233°
July	6	148°	204°	128°	13°	171°	232°
	21	158°	210°	132°	14°	172°	232°
August	6	162°	218°	135°	13°	173°	232°
	21	158°	227°	138°	13°	173°	232°
September	6	149°	237°	142°	12°	174°	232°
	21	145°	247°	145°	11°	175°	233°
October	6	151°	258°	148°	10°	176°	233°
	21	161°	269°	151°	9°	177°	234°
November	6	177°	280°	153°	8°	178°	234°
	21	193°	292°	155°	7°	179°	235°
December	6	209°	304°	156°	7°	179°	235°
	21	227°	315°	156°	7°	179°	236°
Conjunction:							
Superior		—	—	Aug. 8	Mar. 23	Sept. 18	Nov. 17
Inferior		Aug. 29	—	—	—	—	—
Opposition:		—	Apr. 15	Jan. 20	Oct. 2	Mar. 13	May 14

Mercury moves so quickly among the stars that it is not possible to indicate its position on the star charts at a convenient interval. The monthly notes must be consulted for the best times at which this planet may be seen.

The positions of the other planets are given in the table on the opposite page. This gives the apparent longitudes on dates which correspond to those of the star charts, and the position of the planet may at once be found near the ecliptic at the given longitude.

Examples:

(1) *What are the two bright planets, seen near Regulus in the east before dawn on October 5?*
From the table on page 4, the appropriate star chart would seem to be number 1. From this chart it is seen that for the planets to be near *Regulus*, their longitude must be about 150°, and the table opposite shows that the planets are Venus and Jupiter.

(2) *Where can Saturn be found in the third week of September?*
From the table opposite it is seen that Saturn will be approaching opposition, and is therefore visible in the late evening; the longitude is given as 11°. Using charts 8, 9 or 10, as indicated on page 4 for September evenings, Saturn is found to be well up in the eastern sky, below the left hand side of the Great Square of Pegasus.

Phases of the Moon, 1967

New Moon				*First Quarter*				*Full Moon*				*Last Quarter*			
	d	h	m		d	h	m		d	h	m		d	h	m
												Jan.	3	14	19
Jan.	10	18	06	Jan.	18	19	41	Jan.	26	06	40	Feb.	1	23	03
Feb.	9	10	44	Feb.	17	15	56	Feb.	24	17	43	Mar.	3	09	10
Mar.	11	04	30	Mar.	19	08	31	Mar.	26	03	21	Apr.	1	20	58
Apr.	9	22	20	Apr.	17	20	48	Apr.	24	12	03	May	1	10	32
May	9	14	55	May	17	05	18	May	23	20	22	May	31	01	52
June	8	05	13	June	15	11	12	June	22	04	57	June	29	18	39
July	7	17	00	July	14	15	53	July	21	14	39	July	29	12	14
Aug.	6	02	48	Aug.	12	20	44	Aug.	20	02	27	Aug.	28	05	35
Sept.	4	11	37	Sept.	11	03	06	Sept.	18	16	59	Sept.	26	21	44
Oct.	3	20	24	Oct.	10	12	11	Oct.	18	10	11	Oct.	26	12	04
Nov.	2	05	48	Nov.	9	01	00	Nov.	17	04	52	Nov.	25	00	23
Dec.	1	16	10	Dec.	8	17	57	Dec.	16	23	21	Dec.	24	10	48
Dec.	31	03	38												

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The Planets and the Ecliptic

The paths of the planets about the Sun all lie close to the plane of the ecliptic, which is marked for us in the sky by the apparent path of the Sun among the stars, and is shown on the star charts by a broken line. The Moon and planets will always be found close to this line, never departing from it by more than about 7 degrees. Thus the planets are most favourably placed for observation when the ecliptic is well displayed, and this means that it should be as high in the sky as possible. This avoids the difficulty of finding a clear horizon, and also overcomes the problem of atmospheric absorption, which greatly reduces the light of the stars. Thus a star at an altitude of 10 degrees suffers a loss of 60 per cent of its light, which corresponds to a whole magnitude; at an altitude of only 4 degrees, the loss may amount to two magnitudes.

The position of the ecliptic in the sky is therefore of great importance, and since it is tilted at about $23\frac{1}{2}$ degrees to the equator, it is only at certain times of the day or year that it is displayed to the best advantage. It will be realized that the Sun (and therefore the ecliptic) is at its highest in the sky at noon in midsummer, and at its lowest at noon in midwinter. Allowing for the daily motion of the sky, these times lead to the fact that the ecliptic is highest at midnight in winter, at sunset in the spring, at noon in summer, and at sunrise in the autumn. Hence these are the best times to see the planets. Thus, if Venus is an evening star, in the western sky after sunset, it will be seen to best advantage if this occurs in the spring, when the ecliptic is high in the sky and slopes down steeply to the north-west. This means that the planet is not only higher in the sky, but will remain for a much longer period above the horizon. For similar reasons, a morning star will be seen at its best on autumn mornings before sunrise, when the ecliptic is high in the east. The outer planets, which can come to opposition and are then in the south at midnight, are best seen when opposition occurs in the winter months. Clearly the summer is the least favourable time to observe the planets, for the ecliptic is always low in the sky on summer nights.

Notes on the Planets in the monthly diagrams

The following general notes on observing the planets are followed by detailed month-by-month accounts of the behaviour of the planets, and of other interesting phenomena. These monthly notes include diagrams of the planetary orbits, and of the apparent movements of the planets at favourable times of the year. Additional notes on other astronomical phenomena will be found on the following pages.

The monthly diagrams of the orbits of the planets are intended to give a picture of the way in which the planets move about the Sun during the month. These diagrams are similar to those that were given many years ago in the old *English Mechanic*, and which were also adopted for some time in the *Journal* of the B.A.A. The motions of the planets are all anti-clockwise, and the movement during the month is indicated by the thickened line; the longitudes are measured from the Equinox, marked 0°. It is difficult to show all the orbits to scale, since the distance of Pluto from the Sun is about a hundred times that of Mercury. For this reason, only the orbits of the inner planets (Mercury to Mars) are shown to scale, those of the outer planets being merely suggested in the diagrams. A line drawn from the Earth to any other planet will give a rough idea of the apparent longitude of that body, but a more accurate value can be obtained from the table on page 30, and this will enable the position of the planet to be found on the monthly star-charts.

The inferior planets, Mercury and Venus, move in smaller orbits than that of the Earth, and so are always seen near the Sun. They are most obvious at the times of greatest angular distance from the Sun (greatest elongation), which may reach 28 degrees for Mercury, or 47 degrees for Venus. They are then seen as evening stars in the western sky after sunset (at eastern elongations) or as morning stars in the eastern sky before sunrise (at western elongations). The succession of phenomena, conjunctions and

elongations, always follows the same order, but the intervals between them are not equal. Thus if either planet is moving round the far side of its orbit its motion will be to the east, in the same direction in which the Sun appears to be moving. It therefore takes much longer for the planet to overtake the Sun – that is, to come to superior conjunction – than it does when moving round to inferior conjunction, between Sun and Earth. The intervals given in the following table are average values; they remain fairly constant in the case of Venus, which travels in an almost circular orbit. In the case of Mercury, however, conditions vary widely because of the great eccentricity and inclination of the planet's orbit.

			Mercury	*Venus*
Inferior conj.	to	Elongation West	22 days	72 days
Elongation West	to	Superior conj.	36 days	220 days
Superior conj.	to	Elongation East	36 days	220 days
Elongation East	to	Inferior conj.	22 days	72 days

The greatest brilliancy of Venus always occurs about a month *before* greatest western elongation (as a morning star), or a month *after* greatest eastern elongation (as an evening star). No such rule can be given for Mercury, because its distance from Sun and Earth can vary over a wide range.

Mercury is not likely to be seen unless a clear horizon is available; it is seldom seen as much as 10 degrees above the horizon in the twilight sky. In general it may be said that the most favourable times for seeing Mercury as an evening star will be in spring, some days before greatest eastern elongation; in autumn it may be seen as a morning star some days after greatest western elongation.

Venus is the brightest of the planets, and may be seen on occasions in broad daylight. Like Mercury, it is alternately a morning and an evening star, and will be highest in the sky when it is a morning star in autumn, or an evening star in spring. Venus is seen to best advantage when it comes to greatest eastern elongation in June; it is then well north of the Sun in the spring months and is a brilliant object in the sunset sky over a long period.

The superior planets, which travel in orbits larger than that of the Earth, differ from Mercury and Venus in that they can be seen opposite the Sun in the sky. The superior planets are morning stars after conjunction with the Sun, rising earlier each day until they come to opposition. They will then be in the south at midnight, and visible all night. After opposition, they are evening stars, setting earlier each evening until they set in the west with the Sun at the next conjunction. The interval between conjunctions or between oppositions is greatest for Mars (over two years). At the time of opposition, the planet is nearest the Earth, and therefore at its brightest. This change in brightness is most noticeable with Mars, whose distance from the Earth can vary considerably; the other superior planets are at such great distances that there is very little change in brightness from one opposition to another. The effect of altitude is, however, of importance, for at a December opposition the planet will be among the stars of Taurus or Gemini, and can then be at an altitude of more than 60 degrees in southern England. At a summer opposition, when the planet is in Sagittarius, it may only rise to about 15 degrees above the southern horizon, and so make a less impressive appearance.

Mars, whose orbit is appreciably eccentric, comes nearest to the Earth at an opposition at the end of August; it may then be brighter even than Jupiter, but rather low in the sky in Aquarius. These favourable oppositions occur every fifteen or seventeen years (1924, 1941, 1956, 1973), but in this country the planet is probably better seen at an opposition in the autumn or winter, when it is higher in the sky. Oppositions of Mars occur at an average interval of 780 days, and during this time the planet makes a complete circuit of the sky.

Jupiter is always a bright planet, and comes to opposition a month later each year, having moved, roughly speaking, from one Zodiacal constellation to the next.

Saturn moves much more slowly than Jupiter, and may remain in the same constellation for several years. The brightness of Saturn depends on the aspect of its rings, as well as on the distance

from Earth and Sun. The rings are now opening, and the planet is growing brighter at each opposition.

Uranus, *Neptune* and *Pluto* are hardly likely to attract the attention of observers without adequate instruments, but some notes on their present positions in the sky will be found in the March and May notes.

MONTHLY NOTES, 1967

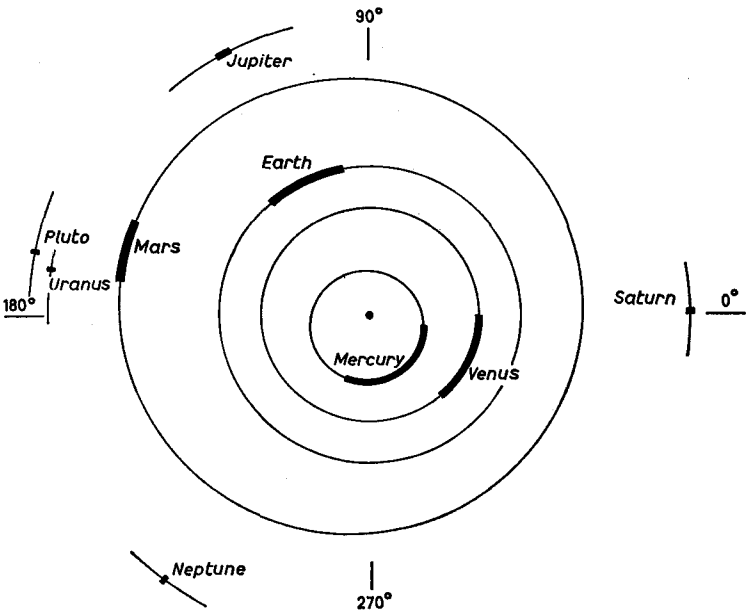
January

New Moon: January 10 *Full Moon:* January 26

Earth is at perihelion (nearest to the Sun) on January 2, its distance from the Sun being then 91,400,000 miles.

Mercury is at superior conjunction on January 18 and will be too close to the Sun to be visible this month.

Venus was at superior conjunction in November and is now making an appearance as an evening star, setting in the south-west more than an hour after sunset at the end of the month. The planet is moving rapidly north and will be a splendid object in the evening sky during the spring and early summer.

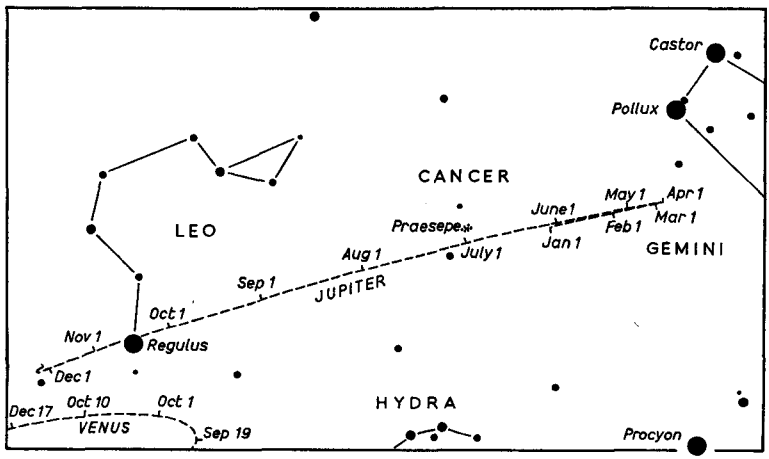


Planetary Orbits in January

Mars is a morning star, moving direct in Virgo and rising about midnight; it is growing rapidly brighter as the distance from the Earth decreases (magnitude +1·1 to +0·6). Mars passes less than half a degree north of the fourth magnitude star Theta Virginis on January 8 (see chart on page 52), and about 5 degrees north of *Spica* on January 18 (magnitudes *Spica* +1·2, Mars +0·8).

Jupiter is at opposition on January 20, and is now visible all night. It will be seen in the constellation Cancer, and at the end of the month will be in line with the stars *Castor* and *Pollux*. Although Jupiter is not as far north as it was in 1965, this is quite a favourable opposition; the magnitude of the planet is −2·2, and its distance at opposition is 398 million miles. The dark evenings afford an opportunity for observing the movements of the four great satellites, all of which undergo eclipses, transits and occultations during the year.

Saturn is an evening star in Pisces, south of the Great Square of Pegasus (see chart on page 64). The planet is almost on the equator and sets in the west before midnight. Although its magnitude is



Jupiter, 1967

only +1·4, it is brighter than any of the stars in this part of the sky.

Jupiter at Opposition. Jupiter, the largest planet in the Solar System, is excellently placed this month. Though it is so far away, it appears very brilliant, and cannot possibly be mistaken; it outshines any other star or planet apart from Venus. (Mars, at its best, can surpass it; but close approaches of Mars are relatively rare, and the next will not occur until 1971.)

From the point of view of the amateur observer, Jupiter is one of the most rewarding objects in the sky. Even a small telescope will show its yellowish, decidedly flattened disk, together with some of the famous cloud belts, and various other features such as the Great Red Spot. Moreover, Jupiter is always changing, and one never knows quite what to expect. In 1963, for instance, the two main equatorial belts merged into one continuous dark band across the equator; this unusual aspect persisted in 1964 to some extent, but by autumn the belts had become separate once more, and in 1965 and 1966 the appearance of Jupiter was much more normal. The Great Red Spot has been prominent for some years past; it is a long-lived feature, and records of it go back as far as 1631, though it did not become really prominent until 1878.

Jupiter rotates rapidly, in only 9¾ hours, but different parts of the disk have different periods. What is known as System I (the equatorial region) has a period about five minutes less than that of the rest of the planet, while various features, such as the Red Spot, have periods of their own and tend to drift slowly in longitude. It is in determining these rotation periods that the amateur worker really comes into his own. The method is to time the moment when the feature under study comes to the central meridian, after which the longitude can be worked out with the help of the tables published in the *Handbook* of the British Astronomical Association.

Since this depends upon visual estimates, the accuracy attainable is quite remarkable; of course, practice is needed, and the work tends to be 'routine', but it is undoubtedly of great value. In

general, a telescope of at least 8 inches aperture for a reflector is needed, but transits may be taken with a reflector as small as 6 inches aperture, though the observations are naturally limited to the coarser features.

The internal constitution of Jupiter is a matter for debate. According to one theory, there may be a central rocky core, overlaid by a deep layer of ice which is in turn overlaid by the hydrogen-rich atmosphere. Alternatively, it has been suggested that the planet is made up primarily of hydrogen all the way through, though near the core this hydrogen is so compressed that it starts to assume some of the characteristics of a metal.

Radio emissions from Jupiter were discovered, quite by chance, in 1955. It was at first thought that there must be certain specific features, such as the Red Spot, which were radio sources, but careful observation has now shown that this is not the case. Another surprise came when it was found that the occurrence of radio bursts from Jupiter was linked with the position in orbit of Io, the innermost of the large satellites; and F. W. Hyde has since (1965) shown that Amalthea, the fifth satellite – actually closer in than Io – is also concerned. At present the whole question of the Jovian emissions at radio wavelengths remains something of a mystery, and further observations are needed before the matter can be cleared up.

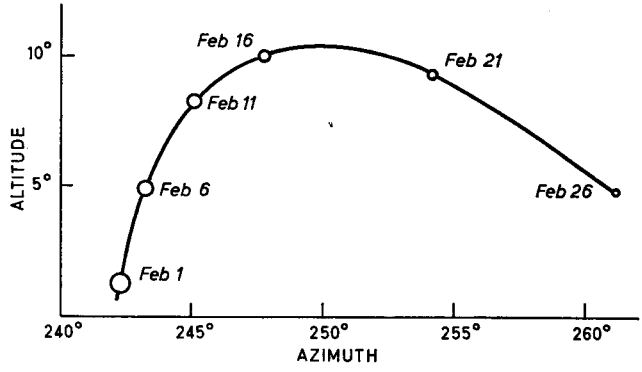
This year Jupiter is in Cancer, and well placed for northern observers. In 1968 it will be in Leo, and still favourably situated; but by 1969 it will have dropped southward into Virgo, after which there will be a period of four or five years when the altitude in the sky, as seen from Europe and the northern United States, will remain inconveniently low. Full use should therefore be made of the next two apparitions.

February

New Moon: February 9 *Full Moon:* February 24

Mercury is at greatest eastern elongation on February 16 (elongation 18 degrees) and this is a favourable opportunity to see this planet as an evening star in the western sky at sunset. The diagram shows the changes in altitude and azimuth (true bearing from the north through east, south and west) of Mercury on successive evenings at a time when the Sun is 6 degrees below the horizon; this will be about 35 minutes after sunset at this season.

The sizes of the circles give an approximate indication of the expected brightness of the planet; it will be noticed that Mercury is much brighter before the date of greatest elongation.



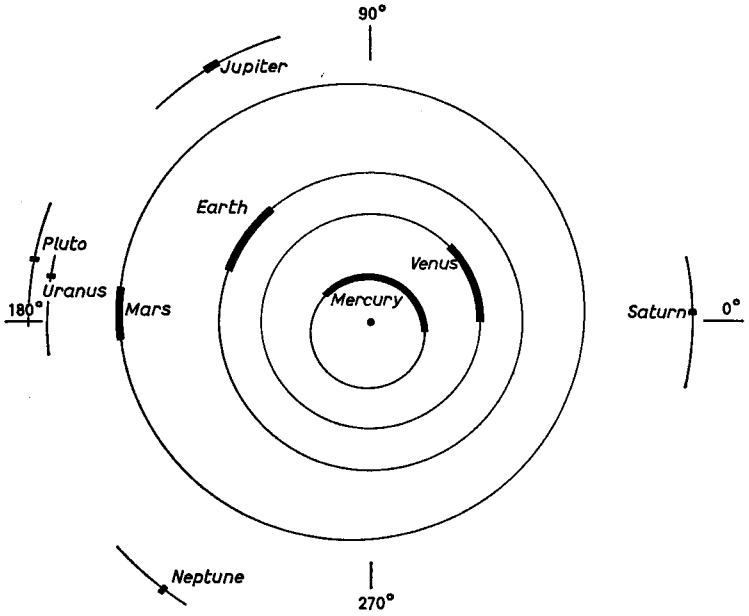
Mercury, February

Venus is a brilliant evening star setting more than two hours after the Sun at the end of the month; it will then have crossed the equator on its way north, and it will be seen to set well north of the Sun. Venus and Saturn will be seen close together in the south-west after sunset on February 23, Venus being the brighter and more northerly of the two planets.

Mars now rises in the east before midnight and grows noticeably brighter during the month (magnitude +0·6 to −0·1). The planet

is a conspicuous object in Virgo, some degrees east and north of *Spica*.

Jupiter is an evening star, setting about two hours before sunrise at the end of February. The planet is still moving to the west (retrograde) and passes into Gemini at the beginning of the month. Magnitude −2·1 to −2·0.



Planetary Orbits in February

Saturn is now moving towards conjunction, and sets only about an hour after sunset at the end of the month. On February 23, Saturn will be seen near Venus in the south-west after sunset (magnitudes Venus −3·3, Saturn +1·2).

The Elongation of Mercury. Mercury, the innermost planet, is never very conspicuous with the naked eye, but when best placed it may be seen easily enough for a short period either after sunset

(in the west) or before sunrise (in the east). In mid-February of this year there is a favourable elongation, when Mercury is an evening star. When seen, it will appear as a reasonably bright star; it will be lower down than Venus, and of course very much fainter.

Unfortunately, a small telescope will show nothing on Mercury apart from the characteristic phase, and serious attempts to see the surface features must be made during daylight, when the planet is high up. This means using a large telescope, equipped with setting circles. It is never wise to sweep around the sky searching for the planet in daylight, since Mercury is always rather close to the Sun—and there is a chance that during sweeps, the Sun will enter the field of view, with disastrous results to the observer's eyesight.

The best chart of Mercury was drawn up 30 years ago by E. M. Antoniadi, using the great 33 inch refractor at Meudon Observatory, near Paris. Antoniadi charted, and named, various dark areas and brighter regions. However, the accuracy of his map is suspect, and further doubts upon it have been cast by the recent American announcement that the rotation period is only 58½ Earth-days; previously it had been thought that the rotation period was 88 days, in which case Mercury would have a 'captured' rotation, and would keep the same face to the Sun all the time.

It must be admitted that amateur equipment is quite inadequate for any useful work with regard to Mercury. However, it is always a source of satisfaction to catch sight of the elusive little planet, and to see its phases.

The Twinkling of Sirius. During February evenings, *Sirius*, the brightest star in the sky, is at its best. From Europe and the northern United States it is never very high up, but its great brilliance makes it unmistakable. Though it is pure white, atmospheric effects make it seem to flash different colours, from red to green. Further comments on this are given in the article on page 157.

The Celestial Unicorn. The area of the sky enclosed by imaginary lines linking *Betelgeuse*, *Sirius* and *Procyon* is largely occupied by the large, dim constellation of Monoceros, the Unicorn. It is not an ancient group; it was shown on the sky-map drawn by Hevelius in 1690, though it may have been formed rather earlier. It contains no star brighter than the fourth magnitude, but it is not nearly so dull and uninteresting as might be thought, since the Milky Way passes through it, and there are many faint stars – together with an open cluster round the star 12 Monocerotis, just visible with the naked eye. Observers equipped with good binoculars or wide-field telescopes will find it well worth while to do some sweeping through Monoceros.

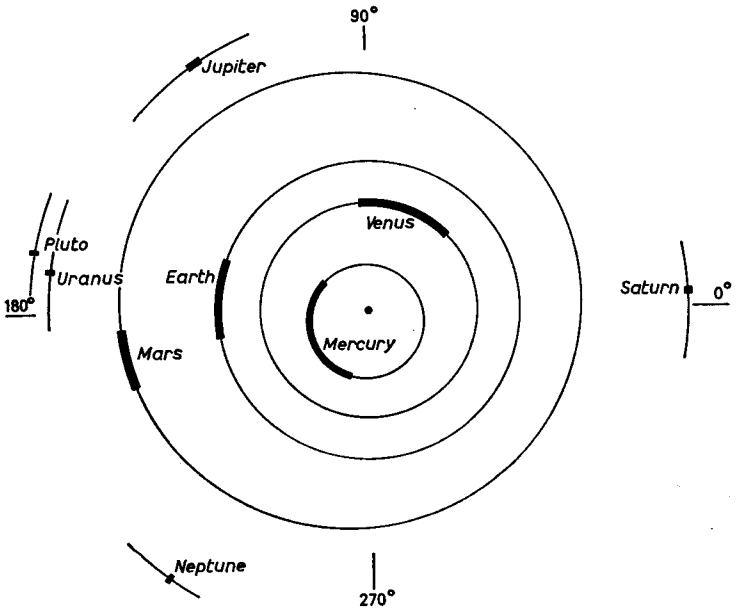
March

New Moon: March 11 *Full Moon:* March 26

Equinox: March 21

Mercury is at inferior conjunction on March 4, and comes to greatest western elongation on March 31. The elongation is then 28 degrees, but Mercury is well south of the Sun and will be too faint to be seen at a low altitude in the dawn sky.

Venus is growing a little brighter (magnitude −3·4) and sets in the west more than 3 hours after the Sun. During March and April the planet may be seen against a dark sky for some time before setting. Venus will be seen near the young crescent moon on the evening of March 13.



Planetary Orbits in March

Mars reaches a stationary point on March 8, near the borders of Virgo and Libra, about 10 degrees east of *Spica*; it then begins to move back towards *Spica*. The diagram on page 52 is on too small a scale to show that the path actually forms a very small loop, the motion for a week or two after the stationary point being very slightly north of the path before that date. Mars grows rapidly brighter during the month (magnitude −0·1 to −1·0) and rises about two hours after sunset at the end of the month. The Moon passes about 2 degrees south of Mars on the night of March 27.

Jupiter also reaches a stationary point during the month (March 21) and will be seen in the south in mid-evening, forming a striking configuration with the Twins, *Castor* and *Pollux*.

Saturn is in conjunction on March 23, and will not be visible during the month. After conjunction, the planet slowly moves out from the Sun to become a morning star.

Uranus is at opposition on March 13 in Leo (see chart on page 52). The distance of the planet at opposition is 1,608 million miles, and its magnitude is then +5·7. It should be just possible to see Uranus with the naked eye; in a small telescope it appears as a greenish disk.

Pluto is also at opposition this month (on March 10) in Leo, and its position is given on the chart on page 52. The planet is too faint to be seen with small instruments, but its position is given in the chart as a matter of interest. Magnitude +15, distance 2,900 million miles.

The First Point of Aries. On March 21 the Sun reaches the celestial equator, after which it will stay in the northern part of the sky until September 23. March 21 is therefore the date of the spring or vernal equinox, and the Sun will lie at what is known as the First Point of Aries.

The positions of celestial bodies are given in terms of declination and right ascension. Declination is simply the angular dis-

tance north or south of the equator of the sky, so that it corresponds to latitude on the Earth's surface (though, rather confusingly, the term 'celestial latitude' has a rather different meaning). The declination of the north celestial pole is, of course, 90°N., and *Polaris* is within 1 degree of this. Delta Orionis, the upper star in the Hunter's Belt, is very close to the celestial equator.

Right ascension is measured from the First Point of Aries. The First Point is simply the place in the sky where the ecliptic (which may be defined as the Sun's apparent yearly path among the stars) cuts the celestial equator. The right ascension of a body is measured in hours, minutes and seconds of time, and is the interval which elapses between the meridian passage of the First Point of Aries and the meridian passage of the star. Thus *Betelgeuse* reaches the meridian 5 hours 53 minutes after the First Point of Aries has done so; the right ascension of *Betelgeuse* is therefore 5h 53m.

The Sun, Moon and planets change their right ascensions and declinations comparatively quickly. The stars, which are to all intents and purposes fixed relative to each other, do not shift so rapidly. The only alterations are due to the effects of precession, or the movement of the direction of the Earth's axis. Because of precession, the polar point – and hence the equator – shifts very gradually, and so the position of the First Point of Aries changes too. In 12,000 years' time the brilliant *Vega* will be the north polar star; when the Egyptian Pyramids were built, the pole star was the comparatively obscure *Thuban* in the constellation of Draco.

The first Point of Aries is no longer in Aries. Precession over the centuries has shifted it into the adjacent constellation of Pisces, the Fishes; and strictly speaking, Pisces should now be regarded as the first constellation of the Zodiac instead of the last. There is no bright star close to the First Point; the position lies between Lambda Piscium (magnitude 4½) and Iota Ceti (magnitude 3½), rather closer to Lambda. In the course of time, the First Point will move out of Pisces into the next Zodiacal constellation, Aquarius.

Two Outer Planets in Leo. Both Uranus and Pluto come to opposition this month, and both are situated in Leo (the Lion), though they are not, of course, really close to each other; Pluto is well over a thousand million miles farther away than Uranus.

Because they are so remote, both planets appear to be slow-moving. Uranus has been in Leo since 1962, and will not enter the next constellation, Virgo, until 1969; Pluto will remain in Leo until 1976.

A modest telescope will show the pale, decidedly greenish disk of Uranus, but Pluto is a very different proposition. It is not a giant, and has a curious orbit of relatively high inclination and eccentricity, so that some astronomers are disinclined to regard it as a bona-fide planet; there have been suggestions that it is merely an ex-satellite of Neptune. However, recent studies indicate that Pluto is at least as large as the Earth, instead of having a diameter of less than 4,000 miles as used to be thought. If so, the idea of its being a former Neptunian satellite is obviously weakened.

Pluto is approaching perihelion, and will be at its closest to the Sun in 1989, when it will actually be nearer to us than Neptune. At that stage it will still be in Virgo, but it is moving slowly southward; and when it reaches aphelion, in the year 2113, it will be so far south that from British latitudes it will not rise at all. Its orbital inclination of 17 degrees means that unlike the other planets, it can move out of the constellations which are conventionally regarded as making up the Zodiac.

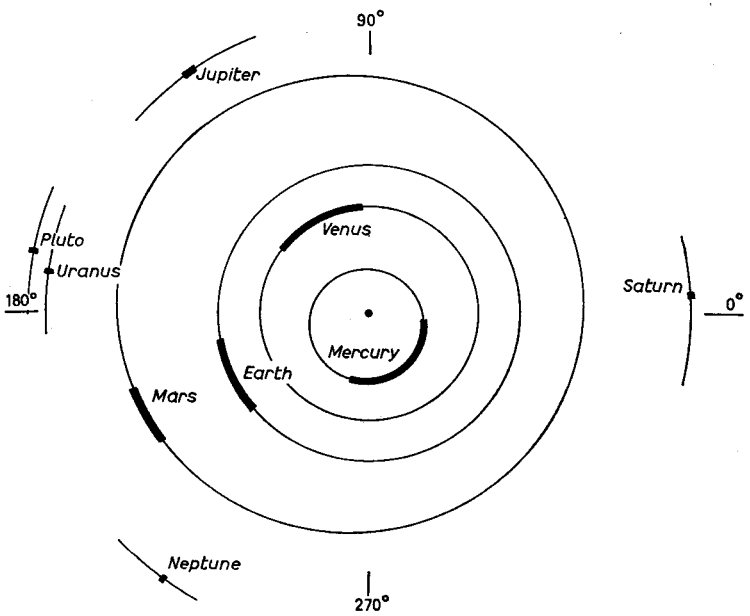
April

New Moon: April 9 *Full Moon:* April 24

Mercury is theoretically a morning star but is too close to the Sun to be seen during April.

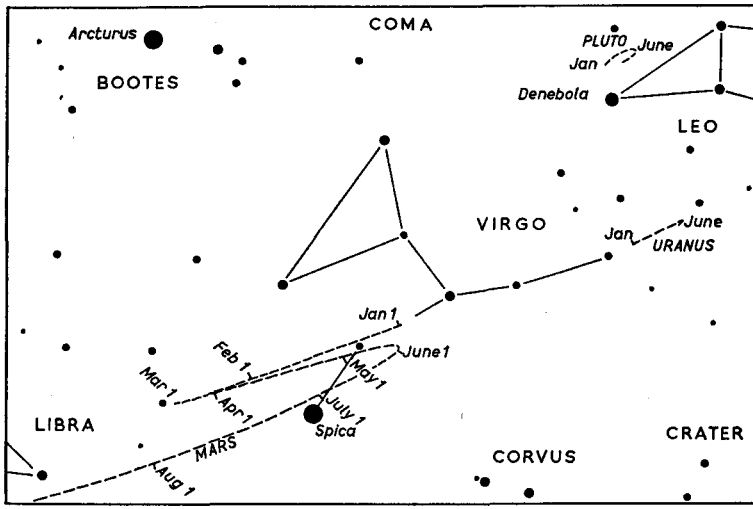
Venus is a brilliant evening star (magnitude −3·5) setting well north of west about 4 hours after sunset. Since it may be seen against a dark sky before it sets, it will be possible to observe its motion among the stars of Taurus. Venus passes between *Aldebaran* and the Pleiades in mid-April, and will be 7 degrees north of *Aldebaran* on April 23.

Mars is at opposition in Virgo on April 15, when it will be at its brightest (magnitude −1·3) and visible in the south at midnight.



Planetary Orbits in April

Owing to the eccentricity of the orbit of Mars, the planet is nearest to the Earth (56 million miles) on April 21. Mars will be quite close to the Moon (nearly at the Full) on April 23, and on the same evening will be about 4 degrees north of *Spica* (magnitudes *Spica* +1·2, Mars −1·3).



Mars, January – August

Jupiter will easily be recognized in the south at sunset. It is moving direct in Gemini, still south of *Castor* and *Pollux*, but it is now fading a little (magnitudes −1·8 to −1·6).

Saturn is a morning star, but moves out from the Sun very slowly. It is a relatively faint object (magnitude +1·1) and is not likely to be seen at all until the end of April.

A total eclipse of the Moon takes place on April 24, but this is not visible from the British Isles. (See page 86.)

Mars at Opposition. Oppositions of Mars come all too rarely to please planetary observers; the average interval between one opposition and the next is 780 days. Thus there was no opposition

of Mars in 1966, and there will be none in 1968. Moreover, Mars is a relatively small world, only 4,219 miles in diameter, so that it can be well studied only when near its best. This year's opposition is moderately favourable, since the altitude is still reasonable for northern observers. In 1969 and 1971 the opposition distance will be considerably less, but Mars will be much farther south in the sky.

At opposition, Mars will be almost exactly as bright as *Sirius*, though it will be higher up than *Sirius* can ever climb in British latitudes, and so will be seen to better advantage. Of course, it is also distinguished by the strong red colour which led to its being named in honour of the God of War.

Small telescopes will show the polar caps and the main dark areas of Mars, but little more; observations of the famous (or notorious!) 'canals' made with small apertures are bound to be highly suspect. The nature of the dark areas is not certainly known. Most astronomers consider that organic matter is responsible, and it is not misleading to speak of Martian 'vegetation', provided that the term is used in a broad sense. Yet the question is far from closed, and it is possible, if not probable, that there is some other explanation which does not involve living matter at all.

Our ideas about Mars needed drastic revision when, in 1965, the American vehicle Mariner IV passed within a few thousands of miles of the planet and sent back pictures showing that the surface is covered with large craters strikingly similar to those of the Moon. There is as yet no general agreement about the origin of these craters. E. J. Öpik, who predicted that craters would be found, attributes them to the impacts of meteorites, whereas others prefer the hypothesis of volcanic action. The question is discussed by Gilbert Fielder elsewhere in this *Yearbook*. If the lunar craters turn out to be volcanic, as seems likely in view of the results obtained from probes in 1966, then it may be assumed that the Martian craters will be volcanic also, but at present it is not possible to come to any final conclusions.

Both Mars' satellites, Phobos and Deimos, are true dwarfs less than a dozen miles in diameter, and telescopes of considerable

aperture are needed to show them. The average amateur-owned equipment is not powerful enough, particularly when, as in 1967, Mars is more than fifty million miles away.

The Eclipse of the Moon. There is a total lunar eclipse of the Moon on April 24, but unfortunately it is not visible from Europe. In fact, 1967 is a particularly bad year for eclipses; none will be seen from any part of the European continent. The next lunar eclipse visible from Britain will be that of 1968 April 13, but even then conditions will not be good, since the Moon will set before the eclipse is over. For the next total eclipse of the Moon really well visible from Britain we must wait until 1975.

Argo Navis. The largest constellation in the sky, Argo Navis (the Ship Argo) was so inconveniently big that it has been officially cut into several parts, of which the most important are Carina (the Keel), Vela (the Sails) and Puppis (the Poop). Carina includes *Canopus*, the brightest star in the sky apart from *Sirius*. However, almost the whole of Argo is too far south to be seen from London or New York. During evenings in March a few stars of Puppis may be seen low over the southern horizon, but *Canopus* and the other leading stars of Argo never rise in European latitudes.

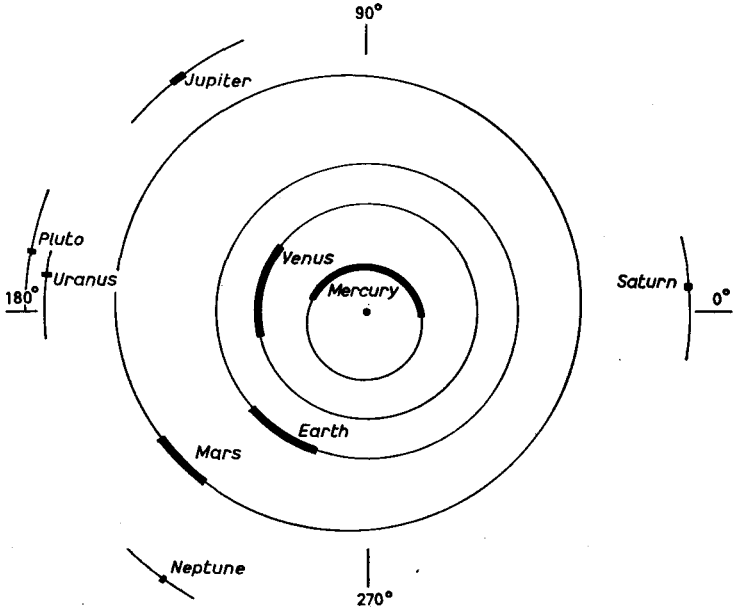
May

New Moon: May 9 *Full Moon:* May 23

Mercury is at superior conjunction on May 11 and will not be seen during this month.

Venus reaches its most northerly point in mid-May and it will then be nearly midnight before it sets, well north of west. The planet is still growing brighter (magnitude −3·7) and is moving through Gemini towards Jupiter; on May 31, Venus passes 4 degrees south of *Pollux*, and Jupiter is then about 10 degrees to the east.

Mars will be found in the south in mid-evening in the constellation Virgo. It continues its retrograde motion, passing about half a degree south of Theta Virginis on May 5, but comes to a stationary



Planetary Orbits in May

point some degrees west of *Spica* on May 27. Mars is fading now (magnitude −1·2 to −0·6) as its distance from the Earth increases.

Jupiter moves into Cancer at the beginning of May and sets shortly after midnight. It is again in line with the Twins, *Castor* and *Pollux*, and will be seen to the left of these stars as they set side by side to the north of west.

Saturn rises in the east about 2 hours before the Sun at the end of May, and will be seen below the Great Square of Pegasus (see chart on page 64). Saturn is well south of the ecliptic and is actually within the borders of the constellation Cetus; it will remain in this corner of Cetus for most of the year. On May 6, Saturn will be seen close to the crescent Moon.

Neptune comes to opposition on May 14 in Libra at a distance of 2,726 million miles. The planet is not visible to the naked eye (magnitude +7·7) but may be seen in a small telescope as a definite disk. See chart on page 72.

The minor planet Vesta is at opposition on May 15, and is just bright enough to be seen by the naked eye (magnitude +5·6) for a week or two before and after this date. The position and motion of Vesta, which is in the constellation Libra, are shown in the chart on page 72.

A partial eclipse of the Sun takes place on May 9, but is visible only in high northern latitudes (see notes on page 86).

Opposition of Neptune. Neptune, outermost of the giant planets, comes to opposition this month. It is situated in the rather obscure Zodiacal constellation of Libra, well to the south of the celestial equator, and is by no means prominent; it is much too faint to be seen with the naked eye, but in a telescope of adequate power it looks quite different from a star. Some people describe its disk as greenish, others as bluish. In every way Neptune is very similar to Uranus, though it is slightly smaller, slightly more massive and considerably denser. Not even giant telescopes will show much in the way of surface detail.

Vesta. Also in Libra, and coming to opposition one day after Neptune, is Vesta, the brightest – though not the largest – of the asteroid swarm. Its diameter is about 240 miles, and it moves round the Sun at a mean distance of 219,300,000 miles, taking 3·63 years to complete one revolution. It was discovered in 1807 March 29, by the energetic German amateur astronomer H. Olbers, who had a private observatory at Bremen, and it has been kept under observation ever since. Actually there is no chance of its being lost, since when at its brightest, as during the present month, it is distinctly visible with the naked eye.

Vesta was the third asteroid to be found; it had been preceded by Ceres (1801) and Pallas (1802), both of which are larger than Vesta, but are further away and not so reflective. According to N. Richter, of the Tautenburg Observatory in East Germany, Vesta has an albedo, or reflecting power, of 25 per cent, as against only 3 for Ceres and 5 for Pallas. These estimates are bound to be very uncertain, but there seems little doubt that Vesta is a better reflector than the average members of the minor planet family, which may indicate that it has a smoother surface. Variations in its magnitude show that the rotation period is about $10\frac{3}{4}$ hours. Of course, it is quite hopeless to look for surface details, and the gravitational pull is too feeble for Vesta to retain any trace of atmosphere. Like its companions in the asteroid swarm, it is lifeless and sterile.

The origin of the asteroids is not known with any certainty. The swarm may be the remnants of a former planet (or planets) which broke up in the remote past; alternatively the asteroids may represent the débris left over when the main planets were born. There seems, in any case, to be no real difference between an asteroid and a meteorite. The total number of asteroids is thought to be well over 40,000, though most of the bodies are small, and even if combined into one globe would not equal the mass of the Moon. Vesta, like all the other asteroids, has an orbit of only moderate eccentricity, and keeps strictly to the region between the paths of Mars and Jupiter.

The Celestial Crow. Corvus, the Crow, may be seen low in the south during May evenings. It contains no star brighter than magnitude $2\frac{1}{2}$, but its four leaders make up a well-marked quadrilateral, and the constellation can be quite prominent, particularly as it lies in a barren region.

To find Corvus, continue the long curve from the Great Bear's tail through *Arcturus* and *Spica*. Corvus will then be found easily enough. The brightest star, Gamma, has the proper name of *Minkar*; it is of spectrum B8, so that it is bluish-white, and is highly luminous. Its distance from us is 450 light-years.

In 1603 Johann Bayer allotted Greek letters to the stars in each constellation, making the brightest star Alpha, the second brightest Beta, and so on. In some cases, however, the order of brightness has not been followed, and Corvus is a good example of this. Following Gamma in order of brilliancy are Beta, Delta and Epsilon; Alpha Corvi is considerably fainter.

Below Corvus is part of the immensely large, very dim constellation of Hydra (the Watersnake). Lower still, and further east, observers in the latitude of London or New York may be able to make out a few stars of Centaurus (the Centaur), but unfortunately the greater part of this splendid constellation is too far south to rise over Europe or most of the United States.

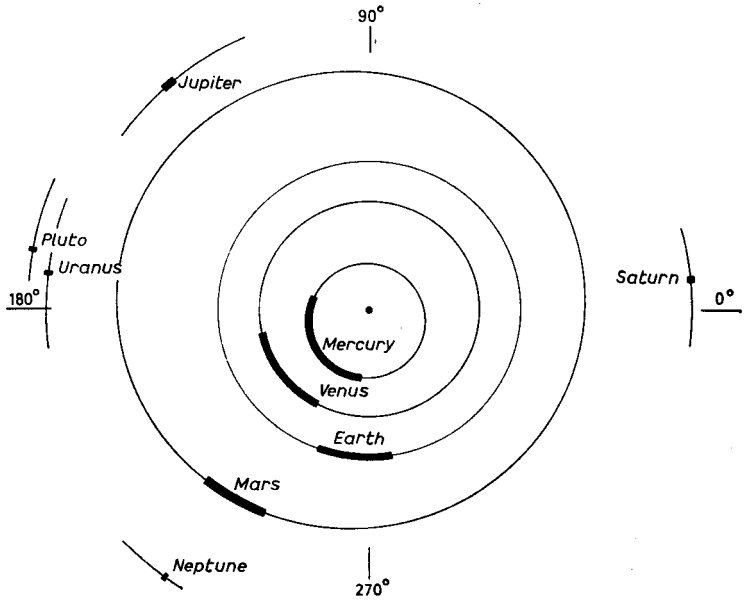
June

New Moon: June 8 *Full Moon:* June 22

Solstice: June 22

Mercury is at greatest elongation east on June 12 (elongation 24 degrees) but at that time the planet is not very bright and although it sets north of west more than 1½ hours after the Sun, it will probably be lost in the bright twilight sky.

Venus is at greatest eastern elongation on June 21 (45 degrees) but now begins to set a little earlier each evening. On June 9 Venus passes less than 2 degrees north of Jupiter and the two brilliant planets will be a notable feature of the evening sky (magnitudes Venus −3·8, Jupiter −1·4). The crescent moon will pass north of



Planetary Orbits in June

both planets on the evening of June 11, and this should be an interesting spectacle.

Mars is still an evening star in Virgo, but is now fading more rapidly (magnitudes −0·6 to 0·0) and sets at midnight by the end of the month. Mars is now moving direct, but is well south of its previous path (see diagram on page 52), so that it passes more than 2 degrees south of Theta Virginis on June 21. The curious shape of the apparent path is due to the fact that Mars passes through its descending node on June 4, crossing the ecliptic from north to south.

Jupiter now sets before midnight. It is moving direct in Cancer, and at the end of the month will be close to Delta Cancri and the star cluster *Præsepe*. The conjunction of Venus and Jupiter on June 9 is referred to above; although both planets are moving direct, the more rapid motion of Venus (more than a degree a day) should be very noticeable.

Saturn now rises more than three hours before sunrise, and by the end of the month it will rise at midnight. It is now a little brighter (magnitude +1·0) and on June 30 will again be seen close to the Moon at last quarter. This is one of a series of close conjunctions of Saturn with the Moon, some of which will be visible in these latitudes.

Præsepe. This month the brilliant Jupiter is close to Præsepe, one of the most famous star-clusters in the sky. This is therefore a good time to look at Præsepe itself, which is a typical open or loose cluster inferior only to the Pleiades in Taurus. (The Hyades, also in Taurus, are brighter than Præsepe, but are decidedly scattered, and so are less impressive.)

Præsepe has been known for a long time, and was referred to by the Greek poet Aratus, about B.C. 280; Aratus wrote that when Præsepe disappeared from view, it was a sign that rain was approaching. In point of fact the cluster can be seen with the naked eye on any clear night, but any mist will obscure it, and neither can it be seen in moonlight. It lies close to two of the stars

in Cancer, Delta (magnitude $4\frac{1}{4}$) and Gamma (magnitude $4\frac{3}{4}$), which are known respectively as Asellus Borealis and Asellus Australis, or the Northern and Southern Ass. Præsepe itself is nicknamed the Beehive.

Galileo, in the earliest days of telescopic observation, counted thirty-six stars in it, though to the naked eye it appears as nothing more than a dim blur. It was catalogued by Messier, and is known officially as M.44. To see it to advantage, a low power with a wide field should be used.

Cancer is one of the faintest of the twelve Zodiacal constellations, but its position between Leo and Gemini makes it easy enough to locate even though its brightest star is only of about the fourth magnitude. Mythologically, it represents a gigantic sea-crab which was sent by Juno, queen of Olympus, to hinder the hero Hercules in a battle against a fearsome serpent (Hydra). Not unnaturally, Hercules stamped on the crab and dispatched it, whereupon Juno elevated it to the heavens!

Venus at Elongation. Venus, which has been a brilliant object in the evening sky for some time past, reaches its greatest elongation on June 21, though it will not reach its maximum brilliancy until late July. The reason for this is that as the planet moves in toward inferior conjunction, its apparent diameter increases, because it swings closer to the Earth. To compensate for this, the phase shrinks, so that whereas Venus appears as a half-moon in mid-June it will be only a crescent by the end of July. However, the increase in angular diameter has the greater effect, and Venus is always at its most brilliant when at the crescent phase. At its best, it may cast a perceptible shadow. If it could be seen fully illuminated against a dark background it would be glorious indeed, but this, naturally, can never happen, since Venus lies within the Earth's orbit.

Vega and Arcturus. Both these two magnificent stars are high up during June evenings, and may be compared in colour and in brilliancy. There can be no doubts about the colour; *Vega's* bluish hue contrasts sharply with the light orange of *Arcturus*. In magnitude, the two are so nearly equal that the star which is the

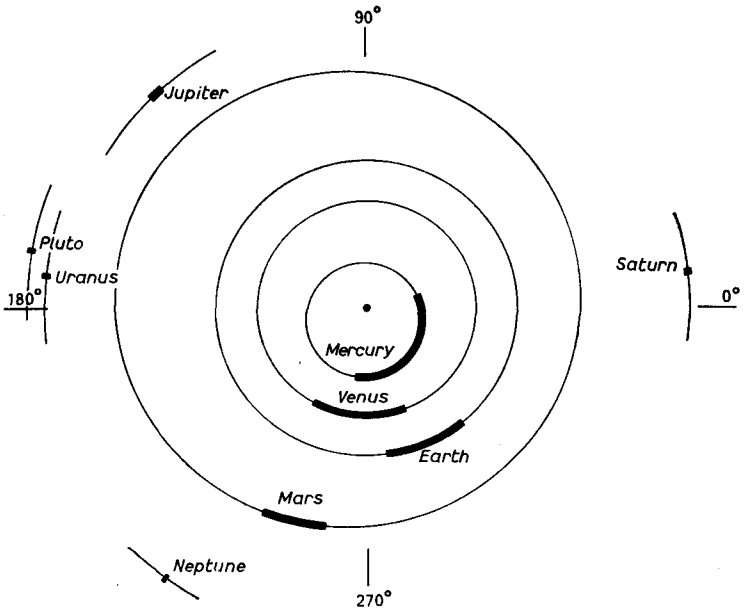
higher will generally appear the brighter. Actually, the magnitude of *Vega* has been measured as 0·04 and that of *Arcturus* at −0·06, so that *Arcturus* is very slightly the superior. Intrinsically it is the more luminous; it equals 100 Suns, whereas Vega is as brilliant as only 50 Suns.

July

New Moon: July 7 *Full Moon:* July 21

Earth is at aphelion (farthest from the Sun) on July 5, when its distance from the Sun is 94,500,000 miles.

Mercury is at inferior conjunction on July 9 and then moves out to greatest western elongation on July 30 (20 degrees). This will give an opportunity to see this planet as a morning star, although observation may be difficult in the bright dawn sky. At a time about three-quarters of an hour before sunrise, the planet will, for several days, have a bearing of about 65 degrees east of north, but it will be brighter in the first few days of August. There will be a better opportunity to see this planet as a morning star in November.



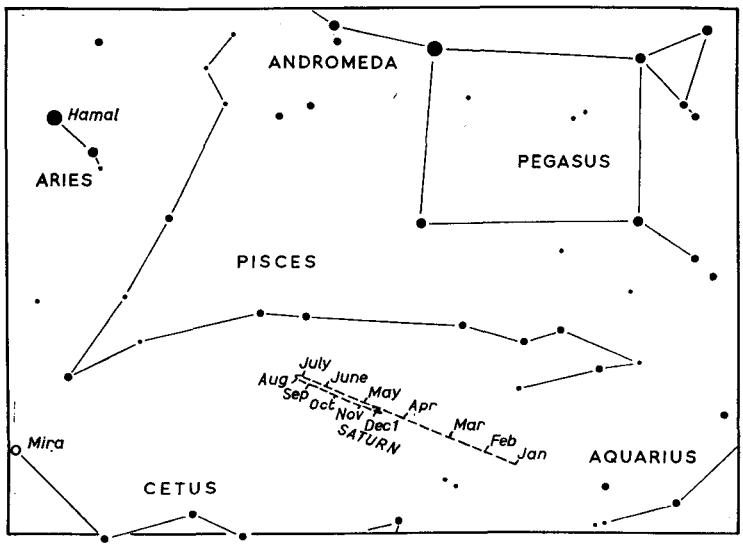
Planetary Orbits in July

Venus will be at greatest brilliancy on July 24 (magnitude −4·2), but it is now swinging in towards conjunction and sets earlier each evening – only an hour after sunset at the end of the month. On the evenings of July 7 and 8, Venus will be close to the star *Regulus*, but the star may be difficult to see against the bright sky without optical aid.

Mars will be seen in the south-west at sunset, and sets about two hours later. The planet is now moving more rapidly east and south, and continues to fade (magnitudes 0·0 to +0·4). Mars passes rather more than a degree north of *Spica* on July 3 (magnitudes Mars +0·1, *Spica* +1·2), the third conjunction of the planet with this star during the year.

Jupiter is moving towards conjunction, and sets shortly after the Sun.

Saturn rises before midnight and reaches a stationary point on July 26 on the borders of Pisces and Cetus. The planet grows



Saturn, 1967

brighter (magnitude +1·0 to +0·9) as the distance decreases and the rings open still wider.

Venus and Regulus. Venus, now a diminishing crescent in the evening sky, will be close to *Regulus*, leader of Leo (the Lion) on July 7 and 8. This recalls the interesting event of 1959 July 7, when Venus actually occulted *Regulus*. The occultation took place in broad daylight, and was of course invisible without a telescope, but it was observed by astronomers in many countries, and careful timings were made.

The main importance of the occultation lay in the 'fading' of *Regulus* before the final disappearance. When the Moon occults a star, the star's brilliance remains steady right up to the moment of occultation, because there is no atmosphere surrounding the Moon's limb. Things are different with Venus, which has a very considerable atmosphere. As expected, *Regulus* faded perceptibly for a few seconds before vanishing, and this allowed astronomers to make estimates of the height of obscuring atmosphere above the surface of Venus. The results confirmed that the extent of Venus' atmosphere is not very different from that of the Earth's, though the composition is by no means the same.

It will be many centuries before Venus again occults a first-magnitude star, and indeed it is not often that even faint stars are occulted by planets. Mutual planetary occultations are even less common, but a few are on record as having been observed; for instance, Venus occulted Mars in 1590 and Mercury in 1737, while in 1859 July 21 Venus and Jupiter were so close together that a telescope was needed to show them separately.

Scorpion of the Sky. Scorpio (or Scorpius) is one of the most imposing of the Zodiacal constellations, though unfortunately it lies too far south to be well seen from the latitude of Europe. It is distinguished by the presence of the famous Red Giant, Antares, which is very prominent low in the south during summer evenings. To either side of *Antares* lie two much fainter stars, Tau and Sigma, each of magnitude $2\frac{3}{4}$. Though these two are so completely outshone by *Antares*, they are in fact highly luminous stars

of spectral type B, and are extremely remote – well over 500 light-years.

Higher up may be seen the line of stars marking the Scorpion's head. Forming a triangle with two of these is a fine globular cluster, Messier 80, which has an integrated magnitude of $7\frac{3}{4}$, and is therefore an easy object in a small telescope, though large instruments are needed to resolve it into stars.

Below *Antares*, Scorpio extends southward to the brilliant 'sting', which contains two stars (Lambda and Theta) not far below the first magnitude. This region is invisible from Britain, but in the southern United States it rises well above the horizon, and is extremely prominent; it is excellently seen from places such as California and Arizona.

In mythology, Scorpio was the creature which inflicted a fatal sting on Orion, the great hunter who had boasted that he could kill any living animal. Subsequently the Scorpion was placed in the sky, but was located directly opposite to Orion, so that the two groups are never above the horizon at the same time – presumably to ensure that the Hunter can come to no further harm!

The Recession of Mars. Mars is now well past its best, and by the end of the month has become considerably fainter than *Vega*. It is still easy to identify, because of its position not too far from *Spica* and because it is so obviously red; but when at its faintest, Mars is not much brighter than *Polaris*, and unwary observers may fail to recognize it.

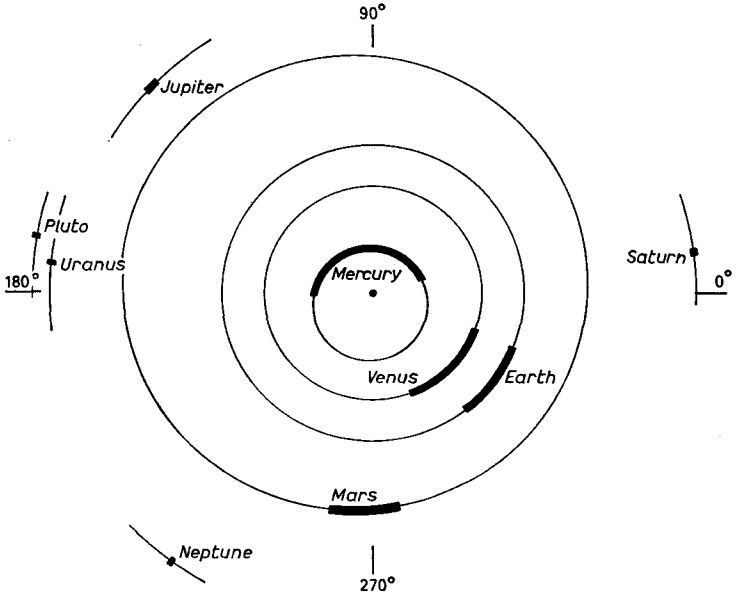
August

New Moon: August 6 *Full Moon:* August 20

Mercury is a morning star in the first few days of August (see notes for July) and is at superior conjunction on August 24.

Venus now sets shortly after sunset and is not likely to be seen. The planet moves rapidly to inferior conjunction on August 29 and after this date it reappears just as rapidly as a morning star.

Mars continues to set about 2 hours after the Sun, and moves into Libra and then into Scorpio. It is now twice as far from the Earth as it was at opposition in April, and is therefore much fainter (magnitude +0·4 to +0·7); but even so it is brighter than any of the stars of Scorpio among which it moves at the end of the month.



Planetary Orbits in August

Jupiter is in conjunction with the Sun on August 8 and after this it becomes a morning star. By the end of August it rises more than an hour before the Sun, and will then be found in Leo, some degrees to the west of *Regulus* and the well-known Sickle.

Saturn rises in the east in mid-evening. It is now growing noticeably brighter (magnitude +0·9 to +0·7) and should be easy to recognize in a part of the sky which contains no very bright stars.

Mars in Scorpio. Mars, still continuing to fade as its distance from the Earth increases, has now arrived in Scorpio. This is an excellent time to compare it with *Antares*, whose name means 'the Rival of Mars'. The two objects are of much the same colour, and Mars is only very slightly the brighter of the two.

The Perseids. August is the best time of the year for observing meteors, since the major shower, the Perseids, occurs during the first fortnight. In 1967 there will be no appreciable interference from moonlight, so that the Perseids may be expected to be really spectacular; they are much more reliable than showers such as the Leonids, which may provide brilliant displays occasionally and be very obscure during other years. Anyone who gazes upward at a dark, clear sky for a few minutes during early August may expect to see at least one Perseid.

Areas of the Constellations. During August, much of the Southern sky during evenings is occupied by large, faint constellations such as Hercules and Ophiuchus. Huge though they are, these groups attract little notice in comparison with much smaller constellations with brighter stars. There is little order and method in the division of the sky into its various constellations; indeed, it has been claimed that the system must have been devised so as to cause as much confusion and inconvenience as possible! Of course, some of the constellations were formed in ancient times – Ptolemy, who died in or about A.D. 180, listed a total of forty-eight – while others have been added much more recently.

Argo Navis, which used to hold pride of place with regard to area, was so unwieldy that it has been unceremoniously chopped

up, and the premier position is now held by Hydra, which however has only one star (Alphard) above the third magnitude. Of the eighty-nine constellations found in modern maps, the smallest is the famous Southern Cross, which boasts of three stars above the second magnitude and another above the third.

The largest constellations are as follows:

Name	*Area, square degrees*	*Two brightest stars, with magnitudes*
1. Hydra	1303	Alpha (Alphard) (2), Gamma (3)
2. Virgo	1294	Alpha (Spica) (1), Gamma (2¾)
3. Ursa Major	1280	Epsilon (1¾), Alpha (1¾)
4. Cetus	1231	Beta (2), Alpha (2½)
5. Hercules	1225	Beta and Zeta (2¾)
6. Eridanus	1138	Alpha (Achernar) (0½), Beta (2¾)
7. Pegasus	1121	Epsilon (2½), Beta (2½, variable)
8. Draco	1083	Gamma (2¼), Eta (2¾)
9. Centaurus	1060	Alpha (0), Beta (0½)
10. Aquarius	980	Beta (3), Alpha (3)

At the other end of the scale come:

1. Crux Australis	68	Alpha (1), Beta (1½)
2. Equuleus	72	Alpha (4), Delta (4½)
3. Sagitta	80	Gamma (3¾), Delta (3¾)
4. Circinus	93	Alpha (3½), Beta (4½)

Orion has an area of 594 square degrees, and comes a mere 25th in order of size, despite its exceptional prominence and its collection of bright stars.

Former star-maps contain various other constellations, some of which were no larger than Crux, but these have mercifully passed into oblivion. A few of the small, faint groups put into the sky by enthusiastic star-charters had barbarous names, such as Sceptrum Brandenburgicum, Globus Ærostaticus and Officina Typographica!

Venus at Inferior Conjunction. During the last days of August Venus reaches conjunction, so that it is almost between the Earth and the Sun. Even with a telescope it is hard to see, partly because it is so near the Sun in the sky and partly because almost all of

its dark side is turned toward us. If the lining-up at inferior conjunction is exact, Venus will be seen in transit against the Sun's disk; but this does not happen often, because the orbit of Venus is appreciably inclined to that of the Earth. The last transit took place in 1882, while the next will not occur until the year 2004.

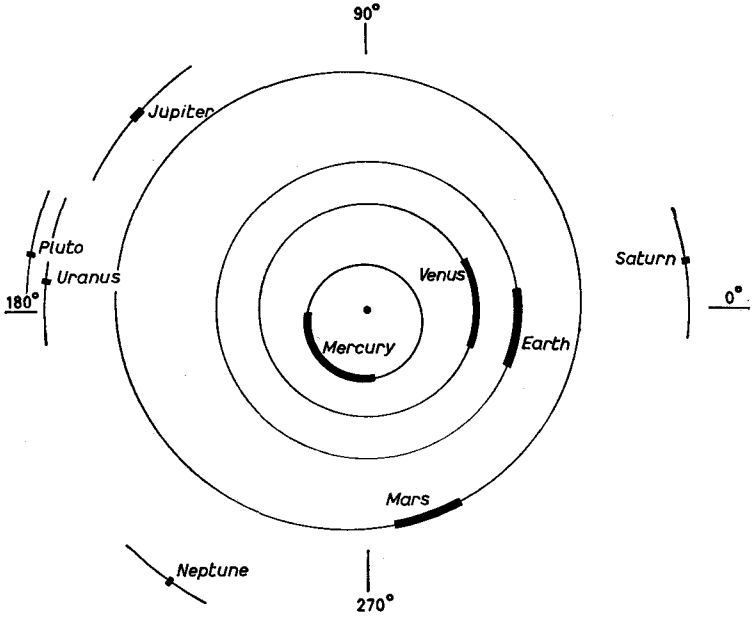
September

New Moon: September 4 *Full Moon:* September 18

Equinox: September 23

Mercury was in conjunction with the Sun at the end of August and will not be seen during September.

Venus makes a very rapid appearance as a morning star; by the end of September it rises more than three hours before the Sun. The motion of the planet is retrograde until September 18, when it reaches a stationary point about 7 degrees south of Jupiter. For some days about this time the two bright planets will be seen to form a striking configuration with *Regulus* and the Sickle of Leo.



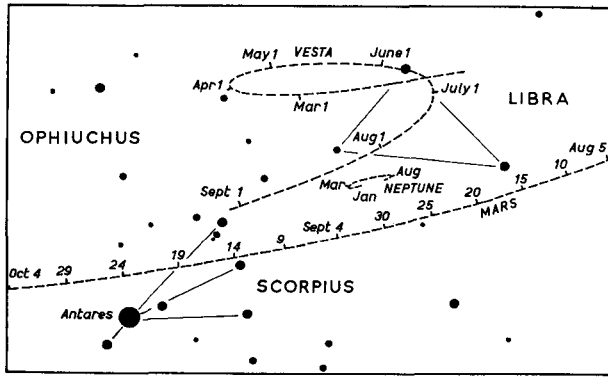
Planetary Orbits in September

Mars is an evening star to be seen low in the south-west after sunset. The crescent moon passes about 1 degree south of Mars on September 9, and on September 23 Mars will be 3 degrees north of *Antares*, the 'Rival of Mars'. This will afford an opportunity to compare their colours; the magnitudes are Mars +0·8, *Antares* +1·2. At this time Mars is actually in the constellation Ophiuchus, which here intrudes across the ecliptic; towards the end of the month Mars passes into Sagittarius.

Jupiter is a morning star, rising about 4 hours before sunrise by the end of the month. It is moving direct in Leo, and there is added interest this month owing to the presence of Venus in the same constellation. There is no actual conjunction of the two bright planets, as may be seen from the diagram on page 40, which shows the movements of the planets at this time.

Saturn is approaching opposition and rises shortly after sunset. It is already brighter (magnitude +0·6) than it was at last year's opposition; this increase in brightness is mainly due to the opening of the rings, which were seen almost edge-on in 1966, but are now inclined at about 7 degrees to the line of sight.

Harvest Moon. The September full moon is always known as Harvest Moon. Most textbooks say that at this time, the Moon



Mars, Neptune and Vesta

rises at almost the same time for several nights in succession. This is not quite correct, but it is true that the 'retardation', or the difference in rising-time between one evening and the next, is less than at any other time of the year, because the angle between the horizon and the ecliptic is at its sharpest.

It is also claimed that the Harvest Moon looks larger than any other full moon. This is quite wrong; there is no difference in apparent size. Neither is it true that the low-down Moon looks larger than the Moon when high in the sky. This is a well-known illusion, but careful measures will show that it *is* an illusion and nothing more.

Fomalhaut. During late evenings in September, the first-magnitude star *Fomalhaut* may be seen low down in the south. It is easy to locate, since two of the stars in the Square of Pegasus (Beta and Alpha) point to it. *Fomalhaut* is the only prominent star in the little group of Piscis Austrinus, the Southern Fish.

Because *Fomalhaut* is so far south, it is never seen to advantage in Britain, and from North Scotland it scarcely rises at all. On the other hand, it is extremely conspicuous as seen from the southern parts of the United States. Not far from it is the constellation of Grus (the Crane), which has a distinctive outline and several rather bright stars, but which is to all intents and purposes invisible from Europe.

The First Point of Libra. The autumnal equinox occurs on September 23; the Sun reaches the equator once more, and passes southward, where it will remain until 1968 March. The autumn intersection between the ecliptic and the equator is known as the First Point of Libra; but just as the First Point of Aries has now been shifted into Pisces, because of precession, so the First Point of Libra has moved into Virgo, and now lies roughly between the two stars Eta and Beta Virginis.

An Astronomical Anniversary. This month marks the centenary of the birth of a well-known American astronomer, Willard James Fisher, who carried out pioneer work in the photography of

meteors and comets, and collected valuable data with regard to meteorites.

Fisher was born at Waterford, New York State, on September 29, 1867. He was educated at Amherst College, and held several lectureships before becoming Research Associate at Harvard Observatory in 1922. Most of his most valuable work was carried out at Harvard, where he was appointed Lecturer in Astronomy in 1928. He died in 1934 September 2.

An Astronautical Anniversary. September also marks a much more recent event – that of 1959 September 13, when the first man-made vehicle landed on the surface of the Moon. This was the Russian probe Lunik II, which was launched on September 12, and duly crash-landed, probably in the region of the great dry plain known as the Mare Imbrium (Sea of Showers). At the time, the voyage of Lunik II was regarded as a major triumph – as indeed it was; in 1959, the Space Age had only just begun, and ideas of manned flight to the Moon were regarded with more than a little scepticism in official scientific circles.

Lunik II carried no cameras, and probably no instruments other than radio equipment, but it showed the way for more sophisticated vehicles. Its signals were followed at the radio astronomy observatory at Jodrell Bank – and presumably in the Soviet Union also – right up to the moment of impact. It was followed, in 1959 October, by Lunik III, which went right round the Moon, and sent back photographs of the averted hemisphere which remained the only ones until the flight of another Russian probe, Zond III, in mid-1965.

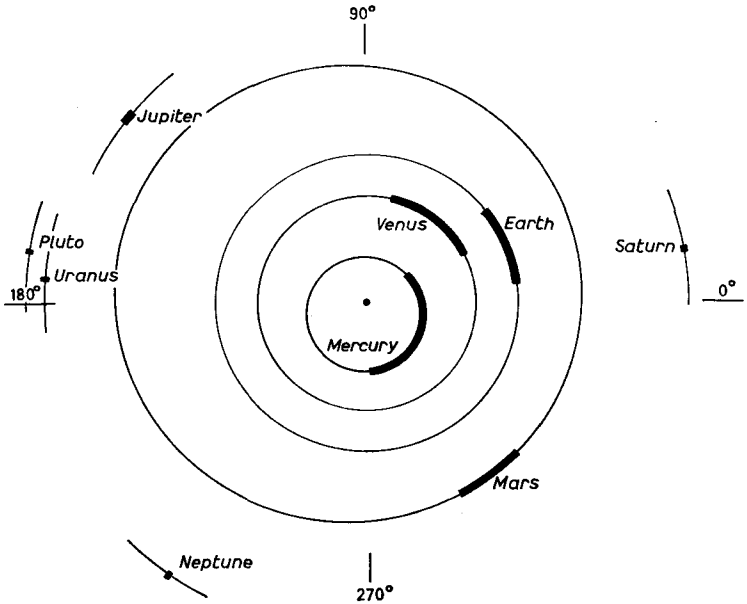
October

New Moon: October 3 *Full Moon:* October 18

Mercury comes to greatest eastern elongation on October 9 (elongation 25 degrees), but the planet is a faint object and is well south of the Sun, so that it is not likely to be seen.

Venus is at greatest brilliancy as a morning star on October 6 (magnitude −4·3) and rises about four hours before sunrise. On October 4 Venus passes about 5 degrees south of *Regulus*, and it should be possible to see this conjunction in a dark sky before dawn.

Mars is still an evening star, setting more than two hours after the Sun. It is now a first magnitude object in Sagittarius and reaches its most southerly point during the month.



Planetary Orbits in October

Jupiter is a morning star, rising in the early hours in Leo. On October 15 it passes about a third of a degree north of *Regulus* (magnitudes Jupiter −1·4, *Regulus* +1·3). Jupiter will remain among the stars of Leo for some months.

Saturn is at opposition on October 2, at a distance of 786 million miles; magnitude +0·6 at the beginning of the month, fading to 0·7 at the end. A small telescope will show that the rings are now open at a shallow angle (about 6 degrees this month) and that the south side is presented to our view. The satellite Titan is bright enough to be seen in quite a small instrument.

A total eclipse of the Moon on October 18 is visible only in the Americas and Australasia (see page 86).

The Satellites of Saturn. Saturn, at opposition this month, is further north in the sky than it has been for some years, and this northward movement will continue, so that conditions for European observers will improve as the years pass by. Moreover, the ring system is now opening out again; the south side is presented, so that before long Saturn will again be a glorious sight in a moderate telescope.

Of its nine satellites, only one (Titan) is really large. The diameter may be well over 3,000 miles, and there is a considerable atmosphere, composed mainly of methane, discovered by G. P. Kuiper in 1944. However, various other satellites are available to users of moderate telescopes. A 3-inch refractor is adequate to show Iapetus and Rhea; Iapetus is very variable, since it is much brighter than when west of Saturn than when to the east. A 4-inch should also show Dione and Tethys, which are closer in. Of the other satellites, Mimas, Enceladus and Hyperion have all been seen with a 6-inch refractor, though not easily; Mimas and Enceladus are inconveniently near Saturn, while Hyperion is best located when near conjunction with Titan. Phœbe, the outermost of the satellite system, is fainter still, and moves in a retrograde direction, so that it may well be a captured asteroid. It is more than 8 million miles from Saturn, and has a revolution period of 550½ days.

The Third Earl of Rosse. There is another important centenary this month. William Parsons, the third Earl of Rosse, died in 1867 October 31, after a career which was of the greatest value to astronomical science.

He was born in 1800 June 17, at York; but he came of an old Irish family, and was educated at Dublin and Cambridge. He became interested in astronomy, and in 1845, at his home at Birr Castle in what is now the Republic of Ireland, he erected a giant reflector with a 72-inch mirror. This telescope was much the largest in the world at that time, and Rosse used it well.

There were many difficulties to be surmounted before the telescope could be brought into operation. Rosse did not have the advantages of a modern-type workshop, or skilled professional assistants; he had to do everything himself, and his helpers were workers from his estate, whom he trained as instrument-makers. The mounting of the reflector was curious, since there were two high walls between which the telescope was placed – resulting in a severe restriction in sky availability. This was unfortunate, but it could not be avoided. The mirror was of speculum metal, and was of good quality for its time.

The greatest discovery made with it was that of the spiral form of some of the objects we now know to be galaxies. Photography was still primitive, so Rosse made accurate drawings, many of which are still of great value.

When Rosse died, in 1867, his work was continued by his son, the fourth Earl, who had been born at Birr Castle in 1840, and who inherited his father's genius. In addition to observing the spiral galaxies, he made the pioneer measurements of heat coming from the Moon. Following his death, in 1908, the observatory was continued for a time, but the last Birr Castle astronomer was a German, and during the first world war all Germans had to be sent back to their own country. This was the end of Birr Castle as an astronomical centre; the great telescope fell into disrepair, and the mirror was removed to the Science Museum at South Kensington, where it still remains. The tube now lies between its stone walls, a monument to the skill and ingenuity of its maker.

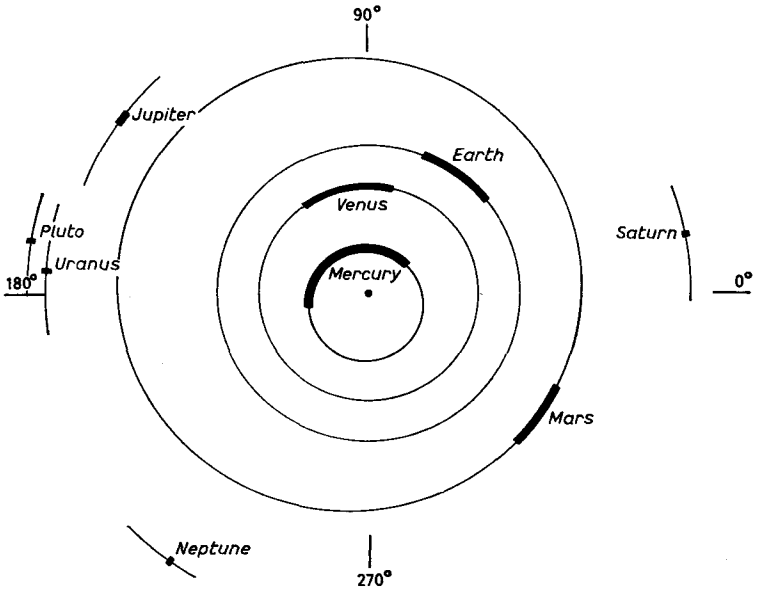
Fortunately, the present Lord Rosse has ensured that the tube is preserved, and the old drawings and relics of the Observatory are carefully looked after. Their historical interest is tremendous.

In 1965 the Royal Astronomical Society met in Dublin, and many Fellows paid a visit to Birr Castle, where they were able to see the remains of the reflector and to pay tribute to the great Irish amateur who died one hundred years ago.

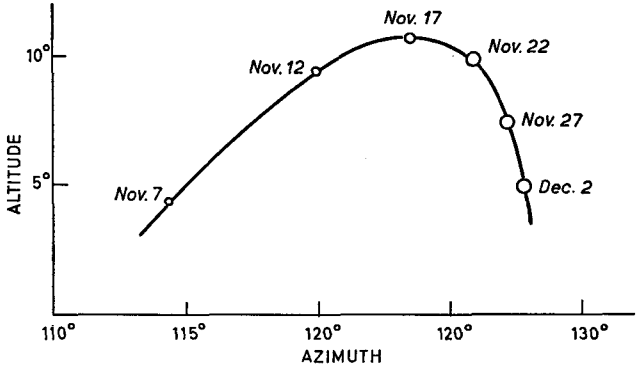
November

New Moon: November 2 *Full Moon:* November 17

Mercury is at inferior conjunction on November 1, and then moves out to greatest western elongation on November 17 (elongation 19 degrees). At this time the planet will be at its greatest northern latitude, and will be well north of the Sun, so that this is a better opportunity than that offered in July to see this planet as a morning star. The diagram shows the changes in altitude and azimuth of Mercury on successive mornings when the Sun is 6 degrees below the horizon; this is about 30 minutes before sunrise at this time of year. The changes in brightness are roughly indicated by the sizes of the circles; it will be seen that Mercury is brightest after the date of western elongation.



Planetary Orbits in November



Mercury, November

Venus is at greatest western elongation on November 9 (47 degrees) and is now a splendid object in the morning sky, rising in the east about 4 hours before the Sun. The planet crosses the equator in mid-November, moving south, but it is still well north of the Sun. Venus passes 0·1 degree south of Uranus on November 7, and 5 degrees north of *Spica* on November 30; these conjunctions may be seen in a dark sky an hour or two before dawn.

Mars may be seen as a first magnitude star in Sagittarius. It is now beginning to move north again, and sets about the same time (19^h) each evening in the south-west.

Jupiter rises at midnight in mid-November below the Sickle of Leo. It is growing a little brighter (magnitude $-1{\cdot}5$ to $-1{\cdot}7$) and is now about the same brightness as *Sirius*. At dawn, Jupiter will be in the south, while Venus, about ten times as bright as Jupiter, will be in the south-east.

Saturn is in the south in mid-evening, and is visible for the greater part of the night. It is still moving retrograde in Pisces, and is fading a little (magnitude $+0{\cdot}8$ to $+0{\cdot}9$) as its distance increases.

A total eclipse of the Sun takes place on November 2, but is not visible in the British Isles (see page 86).

Moonlight and the Leonids. Unlike the August Perseids, the Leonid meteors of November are unpredictable; they have given magnificent displays in the past, but all too frequently they are most disappointing. There are few hopes of seeing them well this year, since the maximum of the shower coincides with the time of Full Moon, and only brilliant meteors will be visible.

A Chance to Locate Uranus. Uranus, the seventh planet, was discovered by William Herschel in 1781, during one of his celebrated 'reviews of the heavens' carried out with home-made telescopes. At the end of the first week in November Uranus will be very close to Venus, and the two planets will be in the same telescopic field, giving beginners a golden chance to locate Uranus without the slightest difficulty.

Cassiopeia. During November evenings the prominent W of stars marking Cassiopeia will be almost at the zenith, and it is worth looking critically at the constellation. It is circumpolar from Britain, so that it is always to be seen whenever the sky is sufficiently dark and clear, and its outline is unmistakable.

Of its five main stars, making up the W, Beta is of magnitude 2·3, Delta 2·7 and Epsilon 3·4. Of the remaining two, Alpha Cassiopeiæ, sometimes still known by its old proper name of *Shedir*, is of about the second magnitude, but is thought to be slightly variable. Former catalogues give its range as from magnitude 2·2 to 2·8, though the Russian astronomer Kukarkin, who drew up an important catalogue of variable stars some years ago, considered that the fluctuations were not real.

Gamma, the centre star of the W, is undoubtedly variable, and has an extraordinary spectrum which makes it difficult to classify. From all accounts, it remained at just below the second magnitude until 1936, when it abruptly brightened up until it surpassed the Pole Star; it reached magnitude 1·6, but then faded down until it had dropped almost to the third magnitude. At present it is usually rather fainter than Beta or Alpha, about equal or slightly superior to Delta.

Needless to say, the stars in the W are not really associated with

each other. *Shedir* is the most distant, lying at 150 light-years from us; its spectrum is of type K, and it is decidedly orange when observed in binoculars or through a telescope. Gamma lies at 96 light-years, Beta at only 45.

Shedir has a ninth-magnitude companion, easy to see with a small telescope, but this is one of the comparatively rare cases in which there is no physical connection. *Shedir* is not a binary; it is an optical double, and the companion is much farther away from us than *Shedir* itself.

The Milky Way flows through Cassiopeia, and the whole region is very rich, so that it is worth sweeping over with a low power and a wide field. In addition, there is a fine binary in Eta Cassiopeiæ, and a fairly bright open cluster, Messier 52, which lies almost in a straight line with *Shedir* and Beta.

Mythologically, Cassiopeia was the proud queen who boasted that the beauty of her daughter, Andromeda, was greater than that of the sea-nymphs. Since the nymphs were the daughters of Neptune, god of the ocean and brother of Jupiter, this was a most unwise claim, and Neptune took the poorest possible view of it, sending a fearsome monster to ravage the queen's land; complete disaster was averted only by the timely arrival of the hero Perseus, who obligingly turned the monster to stone.

This month's eclipse. With typical perversity, the totality track of the November 2 solar eclipse covers only a part of the Earth devoid of land. Totality is visible only from an area of the South Atlantic, and it is hardly likely that any major expeditions will be dispatched to observe it, since there are no convenient islands available. It often happens that the areas of totality are awkwardly placed; astronomers regard this as yet another manifestation of what is known as Spode's Law ('If things *can* be difficult, they *are*').

December

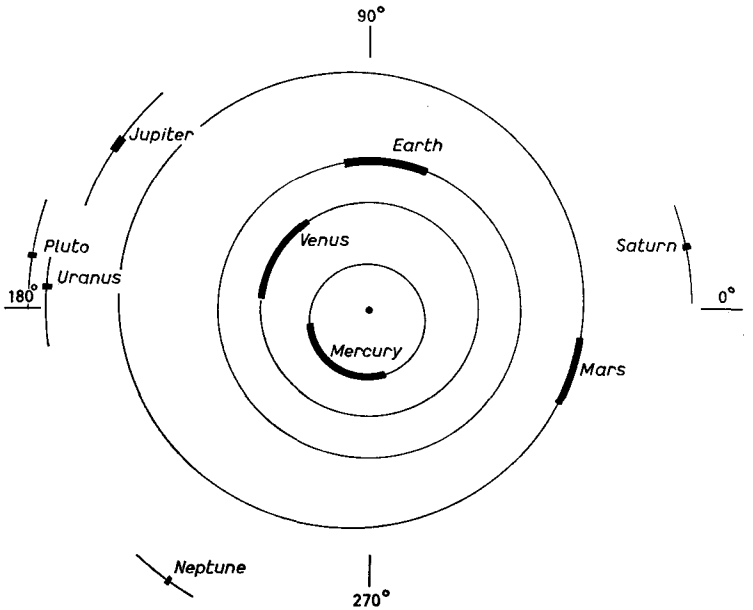
New Moon: December 1 and 31 *Full Moon:* December 16

Solstice: December 22

Mercury is at superior conjunction on December 28, and will be too close to the Sun to be seen during the month.

Venus is still a brilliant object in the morning sky, rising about 4 hours before sunrise. It will continue as a morning star for the first few weeks of 1968, and will be an evening star at the end of the year, but its appearance will not be so impressive as in 1967.

Mars continues as an evening star, passing into Capricornus and setting at about 19^{h}. Although it is at perihelion on December 4



Planetary Orbits in December

(distance from the Sun 128 million miles) it is now rather a faint object of magnitude +1·3. There is no opposition of Mars in 1968, the next one occurring in 1969 May, when the planet will be in Scorpio, at a distance of 45 million miles.

Jupiter now rises before midnight and reaches a stationary point on December 22 below the figure of Leo. The planet continues to increase in brightness (magnitude −1·7 to −1·9) as it approaches opposition in 1968 February.

Saturn reaches a stationary point on December 10 below the left-hand side of the Great Square of Pegasus (see chart on page 64). Although it is less bright (magnitude +0·9 to +1·1) it is still the brightest object in this part of the sky. At the next opposition in 1968 October, Saturn's rings will be open more widely, and the planet will reach a magnitude of +0·3.

The Return of Orion. By December evenings, the brilliant winter groups have again come into view. Of these, Orion is pre-eminent; with its characteristic outline, its prominent stars and its surrounding retinue, it dominates the southern aspect of the sky.

Betelgeuse, the Red Giant in the upper left-hand part of the constellation, is different from the other main stars of Orion, which are hot, white and of early spectral type (O or B). *Rigel*, in the Hunter's foot, has a magnitude of 0·15, so that it is only about one tenth of a magnitude fainter than *Capella* and *Vega*, but when seen from Europe it does not appear their equal, simply because it never rises so high. Yet *Rigel* is vastly more luminous; according to one estimate it is 50,000 times as powerful as the Sun, and lies at a distance of some 900 light-years.

Luminous though *Rigel* is, some of the other stars of Orion are comparable. Kappa or *Saiph*, in the lower left-hand region, has an apparent magnitude of 2·1, so that it is slightly fainter than the Pole Star, but its distance from us is thought to be over 2,000 light-years, and it – like *Rigel* – is a true 'celestial searchlight'. Gamma, or *Bellatrix*, and the three stars of the Belt are also highly luminous. And below the Belt may be seen the Hunter's

Sword, containing the gaseous nebula Messier 42, a superb sight in a moderate telescope. Altogether, Orion lays claim to being the most spectacular constellation in the entire sky.

Mars at Perihelion. By early December Mars has reached its closest point to the Sun. However, it passed opposition as long ago as April, which explains why the apparition was not a really favourable one. Mars has an orbit of decided eccentricity, and its closest approaches to the Earth take place when opposition and perihelion take place at the same time; the slight eccentricity of the Earth's own orbit does not make a great deal of difference. The next close approach will take place in 1971, though the opposition of 1969 will also be favourable. It is a pity that on such occasions Mars is always well south of the celestial equator, so that observers in Europe and the United States are at a disadvantage.

The Christmas Star. Since Venus is now a brilliant morning object, there are bound to be the usual queries as to whether Venus was responsible for the Biblical Star of Bethlehem. The question is natural enough, but the explanation cannot be admitted, because if the Star of Bethlehem had been anything so commonplace as a planet it would have aroused no interest. Neither is it true that the Star was produced by two planets close together, as was once suggested. Other ideas put forward to account for the phenomenon include a nova or supernova; Halley's Comet; and a pair of meteors. However, the evidence is quite inconclusive, and it is impossible to come to any firm conclusions.

Midwinter. The day of the Winter Solstice, December 22, marks mid-winter in the northern hemisphere. The Sun is at its lowest, and from now on will commence to gain altitude. During December, then, the northern part of the globe has less daylight and more darkness than at any other time in the year. After the solstice, those people who live in the Arctic, such as North Canada or North Norway, can start to look forward to the return of the sunlight.

Eclipses, 1967

In 1967 there are four eclipses, two of the Sun and two of the Moon, but none of these is visible in the British Isles.

1. *A total eclipse of the Moon* on April 24, the middle of the eclipse taking place at $12^h\ 07^m$; visible only in the Pacific Ocean, Australasia and eastern parts of Asia.
2. *A partial eclipse of the Sun* on May 9, visible in North America, the northern polar regions and the extreme north of Europe. At maximum phase, which occurs at $14^h\ 43^m$ in the Bering Sea, about 72 per cent of the Sun's disk is obscured by the Moon.
3. *A total eclipse of the Moon* on October 18 is visible in the Americas, the Pacific Ocean and Australasia. The Moon enters the Earth's shadow at $8^h\ 26^m$, and mid-eclipse is at $10^h\ 15^m$; the total phase lasts from $9^h\ 45^m$ until $10^h\ 45^m$.
4. *A total eclipse of the Sun* on November 2 of short duration is visible only in a small area in the South Atlantic Ocean in southern latitudes 60 to 70 degrees. A partial eclipse may be seen in South Africa and Antarctica.

Occultations

In the course of its journey round the sky each month, the Moon passes in front of all the stars in its path, and the timing of these occultations is useful in fixing the position and motion of the Moon. The Moon's orbit is tilted at more than 5 degrees to the ecliptic, but it is not fixed in space. It twists steadily westwards at a rate of about 20 degrees a year, a complete revolution taking 18·6 years, during which time all the stars that lie within about $6\frac{1}{2}$ degrees of the ecliptic will be occulted. The occultations of any one star continue month after month until the Moon's path has twisted away from the star, but only a few of these occultations will be visible at any one place in hours of darkness.

There are only four first-magnitude stars that can be occulted

by the Moon; these are *Regulus*, *Aldebaran*, *Spica* and *Antares*. In 1967 a series of occultations of *Antares* begins, and this star will be occulted each month from some place on the Earth for more than five years. At the present time these phenomena are visible only from the extreme north of Asia and America.

The planets Mars, Venus and Saturn are also occulted several times during the year. None of these phenomena will be visible from the British Isles, but several of the occultations of Saturn may be seen from parts of North America.

Details of occultations of the planets, and of all stars down to magnitude 7·5, as well as possible occultations of stars by planets, are published in the annual *Handbook* of the British Astronomical Association. Similar information applicable to North America is given in the monthly journal *Sky and Telescope*.

Comets in 1967

The appearance of a bright comet is a rare event which can never be predicted in advance, because this class of object travels round the sun in an enormous orbit with a period which may well be many thousands of years. There are therefore no records of the previous appearances of these bodies, and we are unable to follow their wanderings through space. The comets of short period, on the other hand, return at regular intervals, and attract a good deal of attention. Unfortunately they are all faint objects, and are recovered and followed by photographic methods, using large telescopes. Most of these short-period comets travel in orbits which carry them out to the orbit of Jupiter, and it is this planet which is responsible for the severe perturbations which many of these comets undergo.

In 1967 no less than fourteen of these short-period comets are expected to return to perihelion – an unusually large number. The table below gives the names of these comets in order of their periods of revolution about the Sun; the dates of their first discovery and of their last appearance are given, together with the number of returns to the Sun that have been observed.

Comet	*Period (years)*	*First seen*	*No.*	*Last seen*	*Notes*
Encke	3·30	1786	47	1964	A
Grigg-Skjellerup	5·12	1902	10	1961	B
Tempel (2)	5·26	1873	13	1962	
Tuttle-Giacobini-Kresák	5·48	1858	4	1962	C
Forbes	6·42	1929	4	1961	
Wirtanen	6·67	1947	3	1961	
Reinmuth (2)	6·71	1947	3	1960	
Brooks (2)	6·72	1889	10	1960	D
Harrington (2)	6·80	1953	2	1960	
Finlay	6·90	1886	7	1960	
Borrelly	7·00	1905	7	1960	
Arend	7·76	1951	2	1959	
Wolf (1)	8·43	1884	10	1959	E
Tuttle	13·76	1790	8	1939	F

A – *Comet Encke* has the shortest period of any known comet, and is named after the famous mathematician who first computed its orbit.

B – *Comet Grigg-Skjellerup* made a close approach to Jupiter in 1964, and as a result the orbit has become somewhat larger and more nearly circular.

C – The discoveries of this comet in 1858, 1907 and 1951 were all made independently – hence the triple name. The comet was recovered again in 1962 as a result of a prediction, and the orbit is now probably well determined.

D – *Comet Brooks* (2) originally had a period of 29 years, but this was reduced by a very close approach to Jupiter in 1886.

E – *Comet Wolf* (1) has one of the most accurate orbits, thanks to the careful work of the Polish astronomer M. Kamienski. A very difficult object, it may now be too faint to be recovered.

F – *Comet Tuttle* goes out beyond the orbit of Saturn; it was not seen in 1953, and its recovery is of some importance.

In addition to these, *Comet Schwassmann-Watchmann* (1) is certain to be observed. It is visible every year because it travels round the Sun in a nearly circular orbit lying entirely between

the orbits of Jupiter and Saturn. It has a period of 16 years and undergoes remarkable changes of brightness, which seem to have some connection with solar activity.

Predictions have also been made for the return of two of the long-lost comets, *Brorsen* and *Tempel* (1), both of which were last seen in 1879. Three of these 'lost' comets have already been recovered – *Holmes* in 1964, and *de Vico-Swift* and *Tempel-Tuttle* (the comet of the Leonid meteors) in 1965. These recoveries were based on new calculations performed with modern high-speed digital computers, which can cope with cometary perturbations over more than a hundred years in a few minutes. There is every reason to believe that more of these missing comets will be found in the near future.

Meteors

Meteors ('shooting stars') may be seen on any clear moonless night, but on certain nights of the year their number increases noticeably. This occurs when the Earth chances to intersect the orbit of a meteor swarm, which is a concentration of meteoric dust moving in an orbit around the Sun. Such an intersection can occur only at one particular time of year, but if the dust is spread out along the orbit, the resulting shower of meteors may last for several days. The word 'shower' must not be misinterpreted – only on very rare occasions have the meteors fallen so fast as to resemble snowflakes falling.

The naked-eye study of meteors is quite a laborious task, but even a casual observer, watching for, say, ten minutes on an August night, may observe a number of Perseids. If their tracks are marked on a star map, and traced backwards, a number of them will be found to intersect in a point (or a small area of the sky) which marks the radiant of the shower. This gives the direction from which the meteors have come.

The following table gives some of the more easily observed showers, with their radiants; the effect of moonlight in 1967 is indicated.

Limiting dates	*Shower*	*Maximum*	*R.A.*	*Dec.*	*Notes*
Jan. 3–4	Quadrantids	Jan. 3	$15^h\ 28^m$	$+50°$	
April 20–22	Lyrids	April 22	$18^h\ 04^m$	$+33°$	M
July 27–Aug. 17	Perseids	Aug. 12	$3^h\ 04^m$	$+58°$	
Oct. 15–25	Orionids	Oct. 20–21	$6^h\ 24^m$	$+15°$	M
Oct. 26–Nov. 16	Taurids	Nov. 1–7	$3^h\ 36^m$	$+14°$	
Nov. 15–17	Leonids	Nov. 16	$10^h\ 08^m$	$+22°$	M
Dec. 9–14	Geminids	Dec. 13	$7^h\ 28^m$	$+32°$	
Dec. 20–22	Ursids	Dec. 22	$14^h\ 28^m$	$+76°$	

M=moonlight interferes

Minor Planets in 1967

Nearly 2,000 minor planets are listed in the catalogues, but of these only the 'big four', Ceres, Pallas, Juno and Vesta, can reach any considerable brightness, and only the last of these, Vesta, can occasionally be seen with the naked eye.

In 1967 the planet Juno is at opposition in January, but its magnitude is only 7·9. Vesta, on the other hand, will reach naked eye brightness (magnitude +5·6) about the time of opposition on May 15. Its position at this time is shown in the diagram on page 72, and it will be at its brightest during the period of retrograde motion in April, May and June. There are no oppositions of Ceres and Pallas in 1967.

Some Events of 1968

ECLIPSES

In 1968 there will be four eclipses, two of the Sun and two of the Moon.

March 28–29 – a partial eclipse of the Sun, visible in Antarctica, the South Pacific and parts of South America.

April 13 – a total eclipse of the Moon, visible in Europe (including the British Isles), Africa and America.

September 22 – a total eclipse of the Sun, visible only in North polar regions.

October 6 – a total eclipse of the Moon, visible in Asia, America and Australasia.

THE PLANETS

Mercury may best be seen as an evening star at the time of eastern elongations on January 31 and May 24; and as a morning star about the time of western elongation on October 31.

Venus will be a morning star for the first part of the year, and will be an evening star after superior conjunction on June 20.

Mars will not be a very conspicuous object in 1968, since it is in conjunction with the Sun on June 21.

Jupiter will be at opposition in Leo in February 20, and will be in conjunction on September 9.

Saturn will be in conjunction on April 5, and comes to opposition in Pisces on October 15.

Uranus will be at opposition on March 17 on the borders of Leo and Virgo; *Pluto* comes to opposition in Leo on March 12.

Neptune will be at opposition on May 16 in Libra.

Occultations of *Antares* continue throughout the year, and a series of occultations of *Spica* will begin in July.

PART TWO

Article Section

Once again we have kept to the policy of presenting articles on a wide range of subjects. One departure in this issue is the inclusion of something rather more technical – Dr Lindsay's contribution on Quasars, which will, it is felt, be widely welcomed by those readers who are seriously interested in the fundamental problems of modern astronomy.

The articles speak for themselves, but a few biographical notes on contributors may be of interest. Taking the authors in the order in which their articles appear:

Henry Brinton, who has written in most of the previous *Yearbooks*, is an amateur astronomer who has a private observatory at Selsey, in Sussex. He has written many scientific books, though much of his life has been occupied with political activities. He has also written a number of novels. He serves on the Council of the British Astronomical Association.

G. M. Sisson is the managing director of Messrs. Grubb Parsons, and has been mainly responsible for the work on the Isaac Newton telescope, so that one could hardly find anyone more qualified to write upon this subject!

Dr Gilbert Fielder, of the University of London Observatory, is both an astrophysicist and a student of the Moon. Internationally he is regarded as one of the leading authorities on lunar matters, and has been responsible for much original research. He has written several books, some technical and some 'popular' in style.

Dr R. C. Maddison, of the University of Keele, is a physicist with a particular interest in astronomy, and now heads the astronomical activities in the University. He is undertaking research in connection with image converters and similar devices. Dr Maddison has been largely responsible for the development of the observatory at Keele University.

H. G. Miles is Director of the Artificial Satellite Section of the British Astronomical Association, and has also undertaken considerable research in meteoritic astronomy. Professionally, he is a lecturer at the Lanchester College of Technology, Coventry; he is a specialist in computer programming.

Dr E. M. Lindsay has been Director of the Armagh Observatory since 1938. He is a graduate of Harvard, and has specialized in studies of star distribution and the Magellanic Clouds, in which he is one of the world's leading authorities. Much of his observational work has been done at the Boyden Observatory, near Bloemfontein in Africa, which has close links with Armagh, and of which Dr Lindsay was Assistant Director before taking up his Directorship at Armagh shortly before the war.

Sundials

HENRY BRINTON

Astronomy is becoming less and less a matter of looking through telescopes and more and more a question of theoretical physics. It is not a bad idea to take a little time off occasionally to refresh one's memory about the early days of the science, and marvel at the ingenuity and accuracy of the ancients who learned so much about our home in space by employing their crude instruments and turning their native wit to the job of interpreting the results.

One of the first devices to be used was the astrolabe. This is essentially a simple instrument for determining the elevation of a heavenly body. It is possible to make one in a couple of hours; and almost worth doing so to discover for oneself the degree of accuracy which can be achieved by the crudest methods.

The simplest form of astrolabe was a circle, graduated in

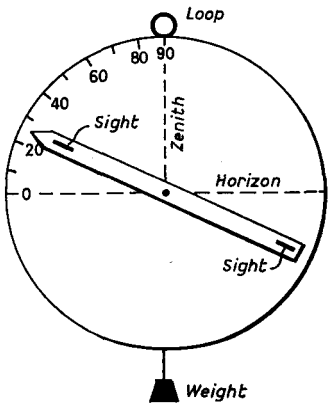


Fig. 1. Simple Astrolabe

degrees, which was held up by a loop at the top and had a weight at the bottom to keep it vertical. Swivelling in the middle was an arm, fitted with sights. The astrolabe was suspended, and the arm pointed at the body whose elevation was to be measured. The elevation was then read off on the circle. The drawing (Fig. 1) makes the process clear.

With a home made contraption of this kind, it is quite easy to determine latitude from the height of the mid-day Sun. Perhaps we should not like to navigate a dangerous landfall in this way; but it is easy to assure oneself that one is, for instance, on the south coast of England, and not on the north coast of France! At the beginning of our era, Ptolemy used an astrolabe to measure the distance of the Moon by parallax, and got the surprisingly accurate answer that it was fifty-nine Earth radii away. When we recall that he cannot have used more than a small part of the Earth's radius as a base-line, we get some idea of how skilfully he must have made and used his astrolabes.

More complex astrolabes were used for other purposes. If the axis is mounted parallel to that of the Earth, and a circle added at right angles to this, we have a form of astro-compass, which can be quite useful to anyone with a telescope mounted on an altazimuth stand. Right Ascension and Declination can be read off, and a star found or identified.

A better known instrument is the sundial, which, for some centuries, was the standard of reference for telling the time. Even after the manufacture of the first clocks, it was the sundial which was used for checking them in the many places where no proper transits were taken.

The sundial, oddly enough, was a far later development than the astrolabe, and we owe it to the ingenuity of the Arabs. For a very long time, simple shadow-clocks had been used, especially in those countries blessed with more than an occasional glimpse of the Sun. The shadow-clock was a mere upright, which cast a shadow on to a dial. Naturally the shadow moved round in a regular way in opposition to the Sun.

Unfortunately, the rate of movement would vary with the

declination of the Sun, and thus a clock accurately graduated for one season would be inaccurate at another. The Arabs deduced from first principles the idea of placing the shadow-casting arm, or stylus, parallel to the Earth's axis, and thus keeping the rate of movement constant at all declinations.

The genius of the discovery may not be immediately apparent; but it is surprising how many people can make and mount a sundial and yet not be able to explain lucidly why it should be mounted and graduated as it is. The principle is easy enough if we look at a rather large shadow-clock on a globe (Fig. 2); but it requires visualizing in three dimensions. The drawing shows the positions of the shadow-clock at an interval of twelve hours.

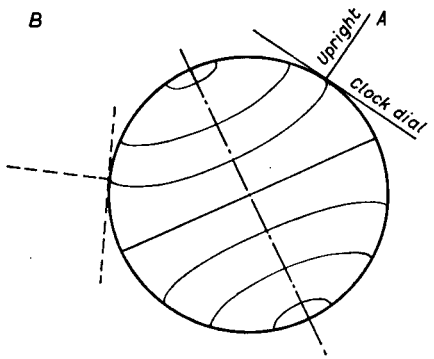


Fig. 2. Shadow Clock (a) at setting up (b) twelve hours later

We can make it a lot easier to visualize if we remember that the diameter of the Earth is negligible, for this purpose, when compared with the distance of the Sun. We can, therefore, imagine our shadow-clock as being at the Earth's centre, and remove the Earth itself. In this case we are not even troubled with the shadow of the Earth, and our clock will work all through the twenty-four hours. This position we see in Fig. 3.

The effect of all this is that the Sun will appear to travel in a circle round the dial of the clock; but the plane of the Sun's apparent orbit will be tilted to the plane of the dial. As the Sun moves,

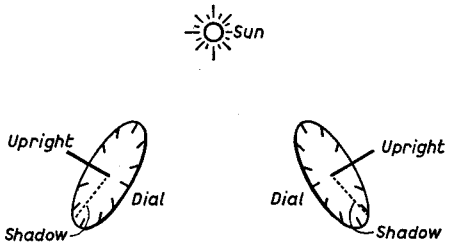


Fig. 3. Shadow Clock with earth removed. Two positions of clock brought close together

the angular distance travelled by the shadow will vary. If the Sun passes very high, the shadow will move slowly, gather speed, and then slow down again.

We can counter this effect by graduating our hour marks, so that the clock keeps time. Unfortunately, the plane in which the Sun seems to move will itself move with the seasons. Our graduations will have to be altered every day, in theory at any rate, and weekly, in practice, if we want our clock to keep even moderately good time.

Now let us mount our shadow clock so that the stylus is parallel to the axis of the Earth, as in Fig. 4. When it has moved through 12 hours, it is still parallel to the axis. If we now imagine it at the

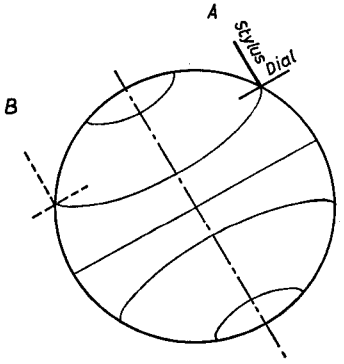


Fig. 4. Sundial (a) at setting up (b) twelve hours later

centre of the Earth, with the Earth removed, the Sun will appear to go round in a plane parallel to the plane of the dial. The shadow, therefore, will move by equal angular amounts hour by hour. We only need to calibrate our dial into divisions of fifteen degrees each, to mark the passage of time in hours.

When the season alters, the circle of the Sun's apparent movement will become higher or lower, but its plane will always be parallel to that of the dial, and the shadow of the stylus, though longer or shorter, will always move at an even angular rate.

A sundial of this sort will be very easy to make. All we have to do is erect the stylus vertical to the dial, and mark the dial out in even divisions. The whole clock must then be mounted (Fig. 5) so that the stylus is set at an angle equal to one's latitude – that is, parallel to the axis of the Earth. It will then keep proper time.

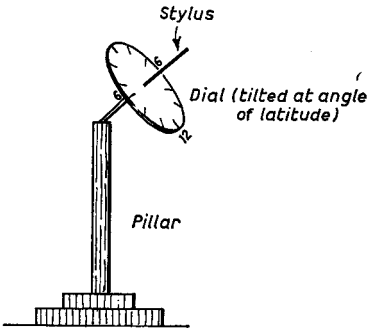


Fig. 5. Simplest form of sundial (shadow on underside of dial for half year)

Such a clock has one slight drawback; for half the year the Sun's rays will be lower than the plane of the dial, and the shadow will fall on the underside. For a short time on either side of the equinox it will be difficult to read the time at all, even by stooping down.

This sort of sundial is the easiest to make, even if not very practical. It also saves the trouble of working out some dodgy

trigonometry before calibrating the hour marks, and helps one to see the principle on which a sundial works.

In order to make the sundial more practicable, at the cost of some calculation, one generally leaves the stylus set at the angle of one's latitude, but moves the dial to the horizontal position (Fig. 6). The clock works in precisely the same way, except that the shadow plane of the dial is not now parallel to the plane of the Sun's apparent movement, and the hour marks must be calibrated to compensate for this tilting.

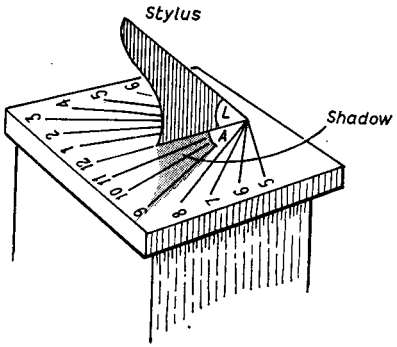


Fig. 6. Ordinary Sundial

This is a matter of simple projection. Without setting out the calculation *in extenso*, we can graduate our scale from the equation:

$$\text{Tan A} = \text{Sin L} \times \text{Tan H}$$

where A is the angle of any given hour mark from noon, L is the latitude of the sundial and H is the hour angle in degrees of the Sun from noon. Thus, if the sundial is at latitude 50° and we wish to find where to mark the figure 3, we deduce that the tangent of the angle at which the figure is to be placed is equal to sin 50° × tan 45°, since the Sun moves through 45° in 3 hours.

It need hardly be added that we told a lie a little earlier. When we said that our first form of sundial would keep proper time, the

qualification should have been added: 'Or very nearly'. Since a civil day is a product of both the Earth's daily rotation, and its yearly rotation round the Sun, we have to allow for the fact that the Earth does not move at an equal rate round the Sun all through the year.

A day is the *average* time from solar noon to solar noon, and this varies by as much as something over a quarter of an hour on either side. To get the right time from a sundial, therefore, one must look up the Equation of Time in an almanac and add or subtract it from the moment shown by the sundial as noon, as the case may be. Naturally, that is not the end of the source of errors. The noon marked by a sundial will not only be inaccurate because of the equation of time. The noon it will show will be local noon. Even in so small a country as England, local noon at Penzance is around twenty minutes later than Greenwich noon.

With all these qualifications, a sundial is still a precision instrument, because the inaccuracies can be allowed for. It may seem a simple and primitive contraption, but, in its way, it is a product of genius. The embryo astronomer can do a lot worse than start by playing around with home-made astrolabes and sundials. He will not do anything of practical value, but he will acquire a familiarity with the intricacies of the Earth's motions. He will also, if he is of a properly humble mind, gain a good deal of respect for the men of ancient times who laid the foundations of the science which is preparing our generation for the excitement of journeying out into space.

The Isaac Newton Telescope

G. M. SISSON

At the time of writing, the Isaac Newton telescope is substantially complete in the workshops. It was ordered for the Royal Greenwich Observatory in 1959 December by the Admiralty, and will be installed on site at Herstmonceux in the summer of 1966. The size of the instrument was governed by the existence of a disk of Pyrex manufactured many years ago in the United States and generously made available to Britain for this project.

Fig. 1 shows the optical system, from which it will be seen that the design will provide a prime focus at F/3 with a correcting lens system, a Cassegrain focus at F/14 and a Coudé focus at F/32. A classical parabola-hyperbola system has been chosen for this instrument. A 3-component correcting lens will afford a useful field 3 inches diameter, equivalent to 35 minutes of arc at the prime focus. Fig. 2 shows a view of the instrument as it will be in the Observatory building, set with its centre of motion at a height of 60 feet above ground level and carried upon a reinforced concrete pier. This drawing shows that the mounting is unconventional in that a polar disk is used instead of a polar axis. This disk affords a strong base from which fork tines can be sprung to carry the telescope tube in the usual manner. The observing floor is set well up within the building, providing convenient access to all parts of the telescope.

The mirror disk is of Pyrex 16 inches thick at the outside edge, weighing some 9,000 pounds and for its support within the cell two new arrangements have been employed. Axial support is by means of three annular air bags behind the back of the mirror. Each bag provides a pressure appropriate to carry the thickness of the glass above the air bag, and due to the concavity in the

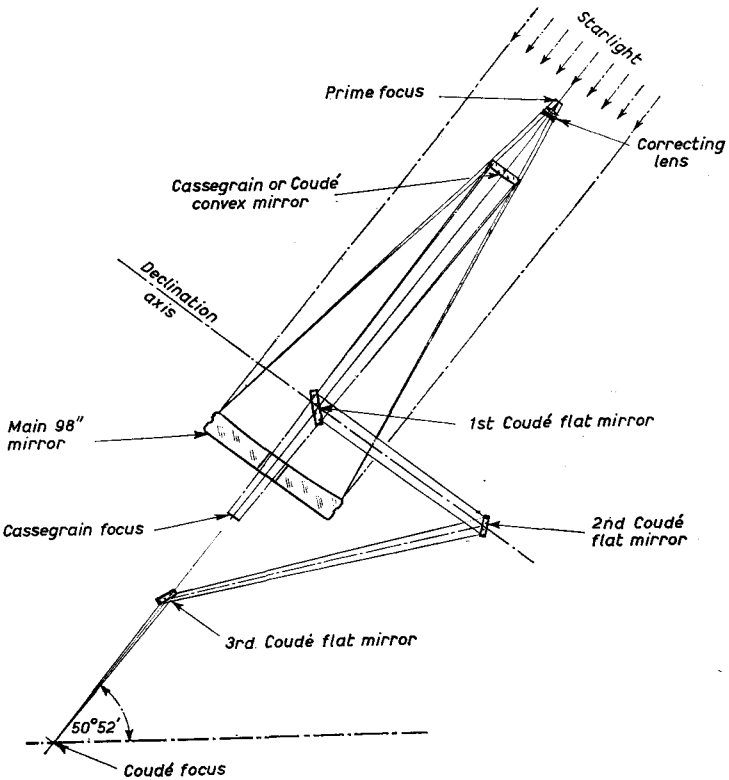


Fig. 1. Optical Arrangement of 98-inch Telescope

front surface this thickness changes by 2 inches from edge to centre. Around the circumference of the bag there are three gaps within which are arranged fixed pads to locate the mirror. It is important that the pressure in the bags be adjusted so that the residual weight carried by these three fixed pads is exactly the correct figure; otherwise triangular distortion would be introduced into the mirror figure. Nominal pressure within the air bag is only 1·3 pounds per square inch at maximum, reducing of course to zero when the telescope is pointing horizontally. At this pressure

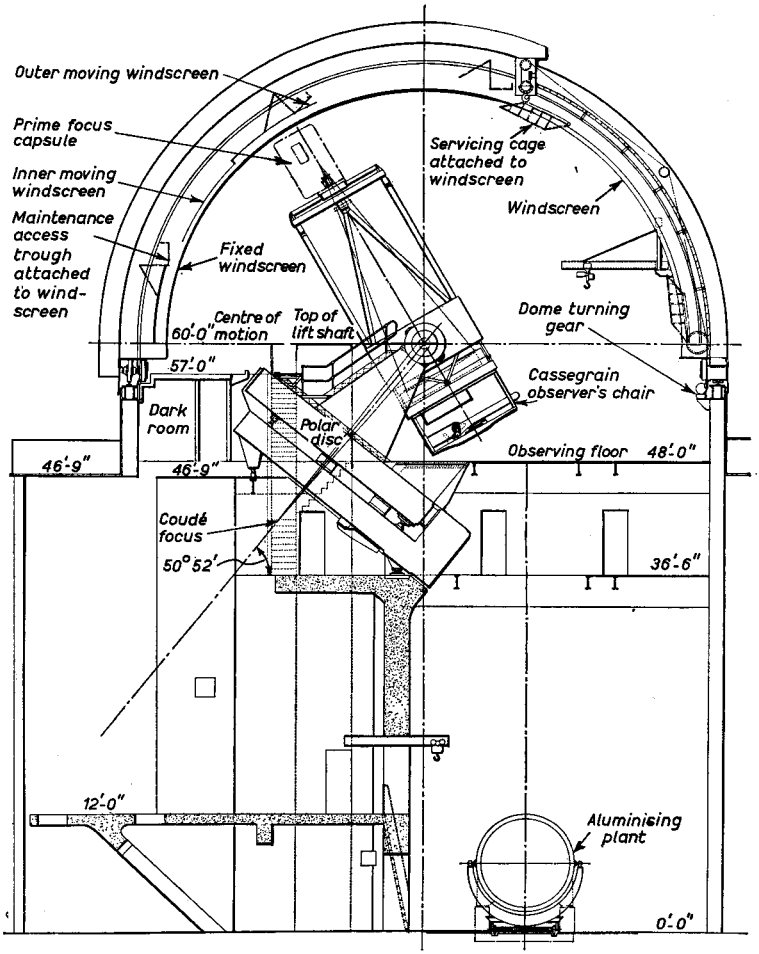


Fig. 2

the bag must provide a support for the mirror of 8,550 pounds with a high degree of accuracy, and this pressure must be changed according to a sine law as the attitude of the telescope changes. A controller comprising a piston with air lubricated walls is used to

govern this pressure, the piston and cylinder being mounted upon the mirror cell; it has been found that by means of this device the support given by the bag is reliably controlled to within ± 1 pound, which is well within practical requirements.

Radial support of the mirror is effected by a system of counter-weighted levers swinging on pivots tangential to the periphery of the mirror. Metal attachments are glued to the circumference of the Pyrex disk, and links join these metal pieces to the levers. These links are radial, and all those above the mirror pull the edge of the mirror radially outwards while those below thrust inwards. The action of the links therefore is to provide a set of radial forces in both compression and tension, varying sinusoidally around the circumference of the mirror. This type of support appears to be theoretically desirable and has been found in practice to give good results on somewhat smaller mirrors. Additional to this weight relief system, there are three thermally compensated pads which bear rigidly against the outside of the mirror and centre it in a precise manner.

Rather elaborate arrangements have had to be provided for working large mirrors and, of course, no suitable machinery can be bought ready-made for such a purpose. A special machine has been designed and built using as a starting point a large vertical boring mill. This machine is now installed within a thermostatically controlled workshop, and is capable of handling mirrors up to over 200 inches diameter. It is a conventional '2 crank' machine but, in this case, the arms driving the polishing tool are operated by hydraulic rams each independently capable of giving an infinitely variable speed and length of stroke.

Testing of the mirror is carried out in a vertical test tower alongside the mirror working shop. After polishing, the mirror is placed upon an air bag on a trolley and wheeled through into the Vertical Test Tower. In this condition it is found that reliable test results can be obtained to yield a knowledge of the surface to within about 1 millionth of an inch. The tower, which is 100 feet high, is provided with floors every 10 feet to suit the various focal lengths of mirrors tested within it. It is double-walled with

thermostatic control, and testing is carried out from an internal steel structure independent of the tower walls to guard against wind vibration. Most of the testing is by means of knife edge pictures and visual assessment using a compensating system to annul the spherical aberration. Zonal errors are evaluated by the measurement of wave sheared interferograms.

The telescope tube is of open type, with tubular A-frames above and below the centrepiece to give equal flexure in the upper and lower sections. When the prime focus is in use, a capsule in which the observer may ride will be fitted to the upper end of the tube. Beneath the main mirror cell an observer's chair is arranged on which the observer will ride when working at this focus. Hollow trunnions sprung from the centrepiece on either side of the tube constitute the declination axis carried by preloaded taper roller bearings in self-aligning housings. The drive to the declination axis is either by means of a tangent screw and arm for slow motion movements or by a large spur wheel for quick motions. Either system can be engaged at will by means of changeover clamps; alternatively, the tube can be left in the free condition to test for balance.

Possibly the most interesting and unusual feature of the design is the use of a polar disk instead of the conventional arrangement of fork tines and polar axis. The disk is a steel fabrication 22 feet diameter $\times$ 3 feet thick, made in three pieces, and weighing altogether some 40 tons. The lower face of the disk has an accurately machined track upon it, and beneath this track there are arranged seven externally pressurized oil bearing pads. Three of these pads are fixed and determine the attitude of the disk; the other four are weight relief pads to support the disk between the fixed ones and minimize its flexure. These weight relief pads are each carried upon a stainless steel bellows; within the bellows a static oil pressure provides the necessary support, and by this means the weight relief is supplied at a constant force without any danger of interfering with the function of the rigid locating pads. The individual pads are circular of varying diameter from 24 inches down to 10 inches, affording supporting forces of 20 tons down to 3

tons. The whole system of pads, oil supply lines and drainage channels is mounted upon a massive mild steel fabricated bedplate set at the latitude angle. This bedplate rests upon three supporting points, one of which carries the majority of the weight while the other two are arranged to be adjustable for setting the polar axis. The whole weight of the moving parts carried by the oil system is about 87 tons. The oil bearings are supplied at a pressure of 200 pounds per square inch, which is reduced by a jet to 100 pounds per square inch within the pressure pool which is actually supporting the disk. Oil escapes continuously around the edge of these pads through the working clearance, which is 4 thousandths of an inch. The design of these pads follows conventional engineering practice, and is such that the clearance is accurately maintained automatically so that the polar disk floats upon a film of oil without mechanical contact with the bearings. Radial constraint of the disk is effected by three pads bearing upon its outer circumference. When first floated, it was observed that half a crown placed at the edge of the disk was sufficient out of balance load to set it moving.

Beneath the polar disk within the ring of supporting pads there is a boss fixed to the disk and carrying the accurate wormwheel and quick motion spur wheel drives. As in the case of the declination drive, a clamping system allows either of these to be used to drive the polar disk at quick motions or slow motions, including, of course, sidereal drive. The wormwheel for the sidereal drive is 12 feet diameter, and has 1,440 teeth. These teeth were cut on a rig in the workshop using two microscopes reading a master circle, each tooth being individually gashed. After this the wheel was free-hobbed and lapped to a condition in which individual tooth to tooth errors do not exceed 0·0002 inches. The worm, which is $3\frac{1}{2}$ inches diameter, engages with a number of wormwheel teeth, and elastic averaging of the individual tooth errors on the wheel provides an overall driving accuracy approaching $\frac{1}{4}$ second of arc for short-term errors.

Coarse and fine synchro-transmitters pick off the angular position of both axes through large spur wheels and suitable gearing.

The information from these transmitters is fed to servo driven dials on the control panel which indicate declination and right ascension to within 1 minute of arc. Digital indication of sidereal time is also provided. Fig. 3 shows the schematic arrangement of the drive to the polar axis. Slow motions are imparted to the worm-wheel (1) by the worm (4). The worm itself is mounted upon a

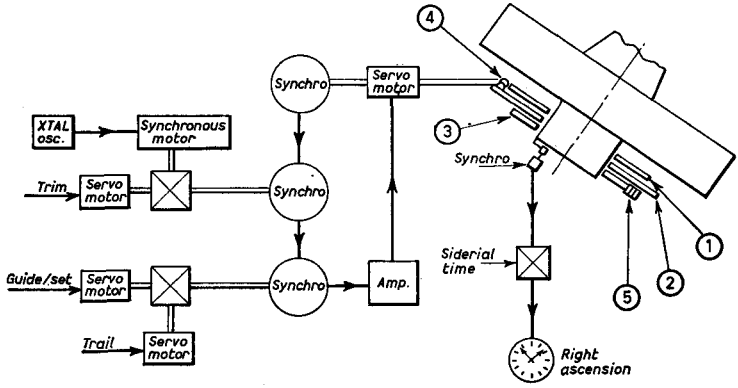


Fig. 3

freely rotating plate (2) linked by a tangential strut to earth. This strut prevents the plate turning but allows it to rise and fall with the polar disk as the oil supply to the pads is turned on or off. The engagement of the worm and wormwheel is critical, and it is most undesirable that it should be disturbed in any way. For slow motion drives the polar disk is clamped to (1).

Also mounted upon the plate (2) is a pinion (5) driving the spur gear (3) and for quick motions the polar disk is locked to this spur gear. The worm is driven by a servo motor with re-setter synchro linked to a control synchro chain within the control panel. The control chain comprises two synchros, each with individual inputs to give different functions. As will be seen from the sketch, the first master synchro receives two inputs from a differential gearbox. These inputs are firstly a synchronous motor driven by crystal oscillator to give basic sidereal rate, and secondly

a small trimming rate given by a servo motor variable between $\pm 0{\cdot}25$ per cent of sidereal rate. The trimming servo motor is infinitely adjustable within the range. The second master synchro likewise receives two inputs through a differential gear box. One of these is a servo motor giving either guiding or setting speeds; these are push button operated at pre-set values which can be adjusted over quite a wide range to suit the user's requirements. The second input is another servo motor to give trailing speeds infinitely adjustable over a wide range. A similar system, but without the basic sidereal rate, is used to control the declination slow motions. The trailing inputs in R.A. and declination can be automatically compounded in any desired ratio to give a star trailing motion in the required direction along the slit which may of course be at any angle relative to R.A. and Dec.

It is hoped that the above description will give readers some information about the main features of this new telescope which will have such an important part to play for astronomy in Britain in the future.

The Craters on Mars

GILBERT FIELDER

On 1965 July 14 *Mariner IV* started to take nineteen historic close-up pictures of Mars, resolving detail down to a few kilometres in horizontal extent. Shortly afterwards, the United States was in possession of coded data which gave, upon processing, intimate views of the planet's surface: the difficult and elaborate experiment enjoyed complete success and the results are of outstanding scientific interest.

Picture-taking commenced in a region centered about 50 degrees of latitude from the north pole of Mars, progressed across the equatorial regions Mesogæa and Zephyria, and, with a gradual turn to the south-east, terminated on the dark side of Mars just beyond the sunset terminator. How have these remarkable pictures – published in *Sky and Telescope* in 1965 (9) – altered our conception of the surface of the red planet?

To the writer, the most surprising thing of all revealed by the new data is the close similarity of Mars to the Moon. In particular, Mars appears to be covered with a variety of craters and rings just like those of the lunar landscape.

Previously, the two worlds were known to be entirely different in appearance: telescopically, Mars had faintly ochre-coloured regions in place of the Moon's virtually colourless continents; Mars, it was known, had an atmosphere and possessed prominent polar caps, but the Moon had neither; and marked changes – some possibly associated with vegetation – occurred on Mars but not on the Moon. In addition, Mars had the well-publicized long, dark, linear canals, and it was not known if the Martian surface were crater-pocked like that of the Moon.

Yet several astronomers predicted that Mars would have its

own liberal covering of craters. One of the earliest predictions of this nature was made by Baldwin (1) who observed that the oases of Mars could conceivably mark large impact craters. Shortly afterwards, Öpik (5) reasoned that asteroidal impacts on Mars might be 1,000 times more frequent than on Earth.

The reason for these early conjectures is readily seen. Many astronomers believe that, during its lifespan of $4{\cdot}5 \times 10^9$ years, the Moon suffered thousands of encounters with asteroidal objects, and that the energy released in the collisions sculptured the giant lunar craters or rings. Mars is considerably closer than the Moon to the densest belt of the asteroids. Many more asteroids intersect the orbit of Mars than that of the Moon, so Mars is the object more prone to collisions. Hence one might expect more impacts per unit of Martian surface than in unit area of the Moon's surface.

Yet Anders and Arnold (2) considered the number-density of Martian craters larger than 20 kilometres in diameter and found it to be only 0·2 of the corresponding figure for the lunar continents. Baldwin (6) arrived at a similar figure for this ratio. In addition, Anders and Arnold calculated the number of asteroidal and cometary impact craters expected to have formed on Mars and on the Moon during their lifetime and, using counts of what were assumed to be impact craters in the lunar maria, estimated that the ratio of observed to predicted craters on Mars was of the order of 10 per cent. Again by comparison with assumed impact craters on the Moon, Witting *et al* (10) arrived at a similar conclusion, but stressed the uncertainty of the underlying assumptions.

Now by calculating the number of asteroidal collisions with the Moon, the writer (7) found that only 10 per cent of the lunar continental craters larger than 6 kilometres in diameter were likely to be impact craters; the implication that the majority of the lunar craters were of internal origin was fully sustained by other evidence. Consequently, the writer cannot accept the foregoing estimates.

Applying a similar procedure to the Moon and Mars, and

including in the statistics cometary nuclei as well as asteroids, Öpik (8) found that, for both the lunar maria and Mars, the observed numbers of craters were in excess of those predicted from the theory of collisions by about 4 or 5 to 1. As these figures are deduced from a method relying on fewer assumptions than that of Anders and Witting, it seems that they may be the more dependable. However, there are uncertain elements in both methods. In short, authors relying on the comparison of assumed lunar impact craters with the craters of Mars have estimated that there are fewer Martian craters than expected as a consequence of impacts, whereas Öpik has found from the present data on interplanetary débris, assumed constant in time, that *Mariner IV* recorded more craters than expected.* Support for Öpik's conclusion emerges from the ensuing discussion of the origin of the Martian craters.

First, it will be of value to examine the newly discovered craters in some detail. There is no clear evidence for craters on frame 1, which was taken through an orange filter with the Sun high in the sky. A few crater-like objects appear on frame 2, taken with a green filter, with the Sun even higher (zenith distance about 15 degrees). Martian craters are clearly delineated on the third frame, taken in green light with the Sun at its highest for the whole series (zenith distance about 10 degrees). Thereafter, two pictures were taken in orange light, two in green, and so on; but in such a way that adjacent frames of different colours overlapped. The colour aspects of the terrain are still being evaluated.

Frame 3 shows some sub-circular craters and one elongated crater-like object measuring approximately 54 kilometres × 28 kilometres. The depression is extended, in the direction of the major axis, by a contiguous satellite-crater – an association reminiscent of some types of lunar formation.

Crater-like objects may be seen on all the subsequent frames

* It might be argued that the sample photographed by *Mariner IV* was not typical, but the cameras crossed both desert and mare topography and, altogether, covered of the order of one per cent of the whole surface of the planet.

up to number 15; frames 16 to 19 have a 'washed out' appearance, whilst frames 20 to 22 were taken beyond the terminator and show no detail.

Sub-circular craters up to 40 kilometres in diameter may be seen in frame 7. In frame 8, the largest completely recorded crater has a diameter of about 50 kilometres and is decidedly polygonal. Part of the floor of this ring – and the whole of the floor of an adjacent ring of nearly equal size – appears to be darker than the surroundings. The pair displays some similarity to Hansteen and Billy on the Moon. There is a suggestion, also in frame 8, of a vast, polygonal depression of the order of 200 kilometres in diameter.

The first clear evidence of objects with central eminences emerges in frame 9, in craters up to 30 kilometres in diameter. These central mountains are like the circular 'knobs' found in lunar craters such as Donati or Faye, which have dimensions similar to their Martian counterparts. A Martian crater of similar type found in frame 10 has, however, an elongated central eminence that is paralleled, significantly, by lineaments outside the crater. Another dark-floored ring, and part of a very large ring-structure, appear in this frame. The ring structure may be 120 kilometres in diameter. The craters in general – and the dark-floored craters in particular – probably show no preference to the brighter or darker regions of Mars, although this point requires corroboration.

The next frame – number 11 – is universally hailed as the masterpiece of the series. It is a green-filter picture made in the relatively bright region of Atlantis, between the dark maria Sirenum and Cimmerium, and the Sun's zenith distance is 47 degrees. This is a region rich in detail on the older maps of Mars, and one corner of the photograph may intersect a dark streak marked prominently on the maps but not in evidence on the photograph. The contrast of the picture is good, and the many clearly depicted craters and ring-structures range in size from 4 kilometres to 170 kilometres. The largest feature is remarkably similar to the same-sized lunar feature Lacus Mortis. The Martian ring has a dark floor with crateriform or scalloped edges. The wall is

incomplete; in part it has a terraced form. It is also strongly lineamented in two directions, and these directions conform roughly to the dark lineaments or canal-like streaks drawn on the Earth-based maps of Mars.

The craters in frames 12 to 16, taken under a progressively lower Sun (zenith distances 50 degrees to 70 degrees) might be expected to cast long shadows but this, it appears, is not the case. According to the team of experimenters, headed by Dr R. B. Leighton (3), even the black zones on the sides of crater walls facing away from the Sun are not true shadows. The dark patches on the prints are merely stretches of terrain inclined at smaller angles to the directions of the incident sunlight than other, brighter patches of surface: the contrast has been increased electronically by an arbitrary extent. It is important to note that the difference of brightness between two separate frames of the published material is meaningless.

To the lunar observer, many of the objects in frames 12 to 16 will appear to be like the 'ghost rings' prevalent in the maria of the Moon. Ghost rings are whitish rings with little or no relief. However, the appearance of these Martian rings may be deceptive. For one thing, the frames were taken between the southern latitudes 35 degrees and 50 degrees, and it is widely recognized that frost could form preferentially in the poorly illuminated zones of crater walls, and hence the observed differential brightness across a given frame would not necessarily relate to the underlying surface materials. The several rings that are recorded on frames 12 to 16 are apparently fragmental in outline, like the rings in the Schröter region of the Moon. Individual bright lineaments may also be seen in proximity to the Martian ghost rings. The lineaments may be ridges. The similar type of topography found in certain parts of the Moon is believed to be the result of faulting and melting by lava flows or the upwelling of lava; or it is thought to be, in part, a consequence of erosion and deposition of the surface materials.

There is certainly an erosive mechanism on Mars. The yellow clouds, composed of dust and water, move at heights of up to 30 kilometres at an average speed of perhaps 30 km/hr. Dust

storms commencing with velocities as high as 100 km/hr have been observed (4). The moving grains and the ice particles in the atmosphere and on the surface of Mars must cause a certain degree of erosion of the surface, and the winds transport the eroded material to other localities. By this means, negative or down-warped regions and graben (if present) would be filled at the expense of higher ground and freshly exposed material on high ground would then suffer further erosion.

Preliminary measurements of the slopes of the crater walls (Leighton *et al*, (3), based on photometric scans made in the direction of the incident sunlight indicate that the average slope of the best-formed walls is about 10 degrees. The horizontal extent of the walls of the largest Martian rings is so great that, on the assumption that the mean slope of the walls is 10 degrees, their altitudes must be directly comparable with those on the Moon. Heights of between 1,000 feet and 10,000 feet must be commonplace. The greatest relative altitude that has been announced tentatively (3), based on the method of photometric profiles, is 13,000 feet, although it should be cautioned that large errors can enter in the determination of slopes and altitudes by this method.

The mean slope of crater walls on Mars is somewhat smaller than the corresponding lunar figure, and might suggest that erosion and transport of material is (as expected) faster on Mars than on the atmosphereless Moon. To offset this effect, the present rate of collision of objects with Mars is greater than the corresponding lunar rate. But the possibility that the rate of destruction of land-forms on Mars is so great that all the craters we see on the *Mariner* photographs are astronomically recent appears to be negatived by the calculations of Öpik. This leaves the question of Martian volcanism and, in the writer's view, there is, in the foregoing observations of the topography of Mars, a considerable amount of independent evidence for volcanoes on Mars.

The evidence is based purely on the morphology and spacial relationships of the Martian surface features and on a knowledge of the origin of similar features and their mutual relations on the

Moon. It is not the purpose of this article to review the indisputably strong evidence for lunar volcanism; a full discussion of this problem has been illustrated in a book (7). However, it is possible, here, to use the knowledge that has been gained by a thorough study of the Moon and apply this knowledge, where appropriate, to Mars. The following broad conclusions may be reached:

The elongated depressions of frame 3 indicate control of crater or ring-structure growth by an underlying fracture or fractures, possibly accompanied by strike-slip faulting.

Rings with polygonal or partly polygonal (segmental) walls may be either impact craters or volcanic structures. If they are impact craters, the shapes were dictated by the directions of pre-existing flow or fracture planes in the rocks of Mars. If they are volcanic, the prime prerequisite is still for planes of weakness in the rocks but, in addition, volcanic materials must have been extruded along these planes and there may have been accompanying collapse of the plug of country rock contained by the ring.

Rings with floors that are darker than the surroundings may be either lava-flooded (as on the Moon) or covered with vegetation. Vegetation might prefer warmer and moister regions, such as the depressed floors of ring-structures.

By analogy with the Moon, the elongated central eminences in frame 10 – and central eminences in general in the Martian craters – are almost certainly volcanic.

The numerous bright linear markings that occur on all the detailed photographs are probably ridge lineaments interspersed with troughs. Of all the structures, they provide the strongest evidence for faulting and volcanic extrusives on Mars.

The suggestion is that hot lavas were intruded along previously existing fractures or faults and some were extruded to build up ridges of volcanic materials on the surface.

If the similarity of form of the 170 kilometres structure (frame 11) to the lunar feature Lacus Mortis is taken to imply a similar origin, then this vast Martian ring is probably a multiply fault-bounded graben-structure with a lava-flooded floor and with satellitic rim-craters of volcanic origin.

The fragmental craters and associated lineamented topography found on the later frames may be explained on the basis of downfaulting and lava flooding, or by the erosive action of ice and other agents that may have operated in the past.

Thus, a strong case may be made for the essentially volcanic nature of the rocks of Mars and, as far as the so-called craters are concerned, arguments for the volcanic origin of some of them are convincing. In addition, these observations provide the reason for the discrepancy between the expected number of impact craters and the number actually observed on Mars: the excess of craters is accounted for by those of internal origin.

Although the literature contains many reports of supposed volcanic activity on the Moon, there are few references to similar outbreaks on the red planet. Only the brightest volcanic flames or the biggest volcanic clouds would be seen on Mars. A large Martian disturbance was seen by a Japanese observer in 1950 and, whilst it may not be possible to reject the hypothesis that this was an impact phenomenon, it may, in the light of the foregoing discussion, be equally reasonable to consider that the observer was witnessing the eruption of a large Martian volcano.

REFERENCES

(1) Baldwin, R. B., *The Face of the Moon*, p. 217, Chicago, 1949.

(2) Anders, E. and Arnold, J. R., 'Age of Craters on Mars', *Science*, **149**, 1494–1496, 1965.

(3) Leighton, R. B., Murray, B. C., Sharp, R. B., Allen, J. D., and Sloan, R. K., 'Mariner IV Photography of Mars: Initial Results', *Science*, **149**, 627–630, 1965.

(4) De Vaucouleurs, G., *Physics of the Planet Mars*, p. 342, Faber, London, 1954.

(5) Öpik, E. J., 'Mars and the Asteroids', *Irish Astron. J.*, **1**, 22–24, 1950.

(6) Baldwin, R. B., 'Mars: An Estimate of the Age of its Surface', *Science*, **149**, 1498–1499, 1965.

(7) Fielder, G., *Lunar Geology*, p. 50, Lutterworth Press, London, 1965.

(8) Öpik, E. J., 'Mariner IV and Craters on Mars', *Irish Astron. J.*, **7**, 92–104, 1965.

(9) Editorial: 'Mariner 4 Photographs of Mars', *Sky and Tel.*, **30**, 155–161, 1965.

(10) Witting, J., Nairn, G., and Stone, C. A., 'Mars: Age of Its Craters', *Science*, **149**, 1496–1498, 1965.

Image Converters in Astronomy

R. C. MADDISON

In science great advances have often been initiated by the development and application of techniques which have either allowed more efficient exploitation of existing knowledge and skills or pushed back the threshold of sensitivity of existing equipment. This is particularly noticeable in astronomy, where direct experimentation is not possible and contact is limited to the collection and study of the various forms of radiation sent out by or reflected from distant objects. At the beginning of the seventeenth century the invention of the telescope, which led to a more efficient use of available light, directly precipitated the great discoveries of Galileo; Newton's early work on colour analysis led to the development of the spectroscope and the subsequent gathering of information on stellar constitutions, temperatures and motions; and the application of photography to astronomy has revealed a picture of an expanding universe of unbelievable proportions.

Present research aims at gathering as much information as possible from very faint sources of light. Great telescopes have been constructed, and sophisticated photographic techniques are employed on a large scale, but even so, most of the available information is being wasted through the use of inefficient detecting and recording methods. If we were able to use all the light transmitted through the Earth's atmosphere to our telescopes, the time taken to amass information on the distant parts of the universe would be considerably reduced and progress would become much more likely. The development of image intensifiers and converters, and their application to astronomy, may go a long way towards meeting this problem of information wastage.

Before describing how these devices can help, it may be useful

to look at the processes involved in the building up and recording of images at very low light levels.

A beam of light may be considered as being made up of a stream of small particles of energy, or photons. The colour of the light is a measure of the energy of the photons, blue light being composed of energetic photons and red light being of weaker photons. The brightness or intensity of a beam of light is determined by the amount of energy striking the detector per second or the rate of incidence of photons at the detector.

Normally the numbers of photons involved in seeing is very large indeed, and the random way in which they are reflected from an object is unimportant when forming an image. Sufficient photons can be detected in a small fraction of a second from an ordinary daylight scene for all the variations in intensity to be faithfully reproduced.

It is a property of statistical methods that deductions become very accurate when the sample used is large enough – in this case the number of photons involved is so vast that the statistical fluctuations in the image are negligible. For very low light levels, for example only fifty photons per second, a scene viewed for a second would lead to an image made up of just fifty bright points which would be scattered widely and would be practically impossible to interpret. A complete image may be considered as an array of millions of such bright points, the brightness of each depending on how many photons are incident at that point. In this way it can be seen that the important quantity determining image detail and recognition is the total number of photons recorded. The low light level scene considered above could be fully recorded if the detector were exposed to the radiation for a much long time.

Astronomically, the situation may be made easier by using large telescopes, very sensitive films and exposures running into many hours, but this is costly and inconvenient and does not go to the heart of the problem. Most effective improvements can be made in the initial methods of detecting photons and converting them into a permanent record.

Existing photographic processes depend on a type of chemical sensitivity that is induced in a film emulsion when it is exposed to light. Such emulsions are usually made of millions of tiny crystals of silver salts held in a thin layer of gelatin, and exposure to photons causes the release of metallic silver particles which may be made visible by subsequent chemical development and fixing. The amount of blackening of a film is proportional to the number of photons collected, provided that this number is not excessive. It is found, unfortunately, that the response of a film falls off with exposure. This is not surprising for excessive light levels when one remembers that there is a finite number of silver grains at any point on the film, and that when all have been blackened the film will fail to detect. It is surprising, however, for low light levels, and it seems that the latent chemical image slowly decays or leaks away by some process that is not fully understood. The fall-off in sensitivity of emulsions with exposure is often referred to as 'failure of the reciprocity law' or more simply 'reciprocity failure'.

The major limiting factor in the photographic process is the efficiency with which photons are converted into detectable grains of silver. For the most sensitive emulsions the average number of photons required to yield a single image point is about one thousand. In practice the efficiency of this conversion process is expressed as the average number of detectable grains or image points formed by one incident photon, and this number is called the quantum efficiency. A perfect converter would have a quantum efficiency of 100 per cent, whereas the best photographic materials have quantum efficiencies no greater than 0·1 per cent.

Fortunately, photo-chemical action is not the only method of registering the small amounts of energy that are carried by electromagnetic radiation. Towards the end of the last century Hertz showed that electrons could be ejected from certain metallic surfaces under the action of light. This photo-electric effect has been studied in great detail, and the last few years have seen the development of photo-sensitive layers having quantum efficiencies as high as 20 per cent for some ranges of colours. The conversion process in this case is from incident photons into electrons leaving

a photocathode, and the process is more than 100 times as efficient as the photographic reaction. In addition, the end-product is in a form that is much more convenient to handle and may be readily amplified in some form of cascade multiplier.

Photo-emitters have further advantages over conventional photo-chemical detectors. The photocathodes used are generally thin films of evaporated metals for which the effective grain size is the minimum area from which electrons may be emitted. These areas are very much smaller than the smallest silver salt crystals in the finest grain emulsions, and the optical resolution is correspondingly greater at this stage.

A consequence of improved resolution and quantum efficiency is that photo-electric devices are able to discriminate fainter sources against bright backgrounds. A greater number of photon-electron conversions can be recorded per image point than is possible in the photographic case, and the signal to noise ratio is consequently higher.

Finally, photo-emitters behave in a linear fashion, and there is no reciprocity failure as there is for photographic emulsions. This means that, if a suitable recording unit is devised, the exposure time that can be effectively used should be limited only by the background noise level against which objects are viewed.

Early photo-electric devices were limited to the silver-oxygen-cæsium type of photocathode introduced in 1930 by Koller. These photocathodes did not represent a significant advance on existing photographic materials, because of their low sensitivity. Maximum efficiency was in the infra-red region of the spectrum, and they were therefore subject to high noise levels at room temperature. The development of the cæsium-antimony photocathode by Görlich in 1936 was the real starting point for the great advances of recent years.

Semiconductors provide the best type of electronic structure for photo-emitters in the visible region of the spectrum. This is due to the fact that the energy barrier at a surface, facing escaping electrons from within the structure, is lower than the amount of energy that can be taken in by the absorption of a single photon.

This barrier is suitably small for materials with low electron affinities, and it is found that highly efficient emitters can be made from films containing mixtures of alkali metals, antimony, bismuth, silver and oxygen, although the exact proportions of constituents for a particular photocathode are still found largely by empirical methods. Painstaking experimentation has led to the construction of some cathodes, for example the multi-alkali one – (Cs) $Na_2K.Sb$., having quantum efficiencies as high as 30 per cent for some colours.

Most of the problems associated with the focusing of electrons and the building of highly-corrected electron lenses had been solved by the beginning of the second world war, and much of the research effort had been directed towards the development of cameras for television. The situation at the end of the war was that good photocathodes were readily available, good electron-optical systems had been developed and several research groups were investigating the various types of image receptor that could be used as recording units for the new image converters and intensifiers.

Basically, a converter will achieve some gain if more photons are emitted from the receptor per incident electron than were required to release each electron from the photocathode. This is possible if the electrons pick up enough energy as they move across the evacuated container under the influence of strong electrostatic or magnetic focusing fields. The electron image exists as a space current moving towards a receptor anode, and, if some form of space current amplifier can be introduced, very high gains may be obtained and the device is known as an intensifier.

Of the many lines along which the development of receptor units has been progressing four may be selected as representing the main types. The simplest classification is as follows:

(*a*) Electronographic methods where the electrons are detected directly by photographic means.
(*b*) Cascade devices employing phosphors.
(*c*) Electron storage techniques involving scanning systems.
(*d*) Solid state devices.

Each of these will be described in more detail.

(*a*) Electron cameras, as the name suggests, use photographic techniques to record the accelerated photo-electrons directly. The idea was originally suggested by Lallemande in 1936, and he has been responsible for perfecting the design of what must be regarded as one of the most promising devices for astronomical work.

A diagram of the Lallemande camera is shown in Fig. 1. The

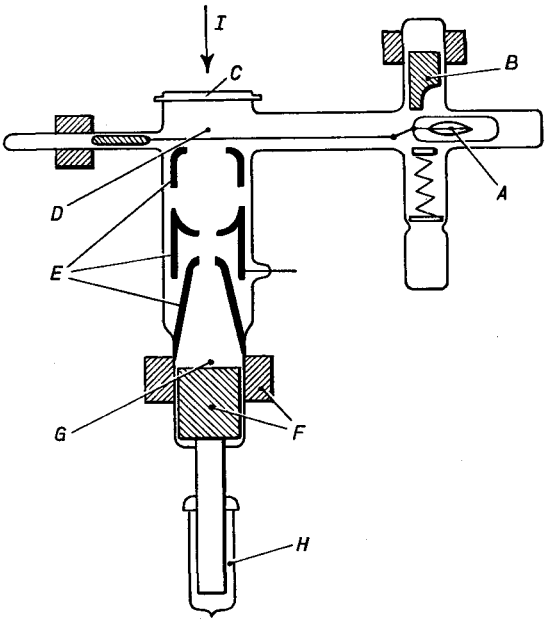


Fig. 1. The Lallemande Electronic Camera

A. Ampoule containing photocathode on glass lens
B. Magnetically operated hammer for breaking ampoule
C. Optical window for light from telescope
D. Operating position of photocathode
E. Electron lenses
F. Electrically operated plate magazine
G. Electron image position
H. Liquid air container
I. Incident light beam

whole complex glass envelope containing the electrically operated plate magazine is processed and evacuated on a separate vacuum system, and the sensitive photocathode unit is pre-fabricated and enclosed in a thin glass ampoule which rests in a side-arm of the main tube.

When the camera is ready for use, the ampoule is broken by means of a magnetically operated hammer and the photocathode is magnetically drawn into position under the optical window and in the image plane of the telescope.

In order to match the optical image curvature to the electron lens surface, the photocathode is deposited on the back face of a glass lens of appropriate focal length.

During operation the photo-electrons are focused and accelerated towards the photographic plate which is cooled with liquid air. Cooling enhances the sensitivity of the emulsion, and is essential in suppressing the evolution of gases from the plates. Cæsium is chemically highly active, and the efficiency of the photocathode falls off rapidly with deteriorating vacuum conditions and contamination.

The photographic plates used are those that have been developed for nuclear research, and they are highly sensitive to electrons and relatively insensitive to light.

The gain of the camera lies in the combination of high quantum efficiency with the ability of the plates to record single electron impacts. When the lenses are operated at an accelerating voltage of 25,000 volts, each electron produces ten to fifteen silver grains along a short track in the emulsion. Comparison of the results with those obtained ordinarily using Kodak 103a-0 plates shows that there is an initial gain in speed of 10,000 and a gain in resolution of 10. Unfortunately, since the receptor is photographic, there is the attendant reciprocity failure, and it is found that the gain in speed after an hour is reduced to about 40.

Lengthy exposures with this type of camera lead to a phenomenon known as the 'ionic spot' on exposed emulsions. It is not possible to produce a perfect vacuum, and the high energy electrons frequently collide with residual gas atoms causing ionization.

The lens system focuses electrons only, and any positive ions are attracted towards the photocathode. Foreign electrons produced by gas ionization tend to concentrate on the electron-optical axis and blacken the centre of the emulsion.

The major disadvantage of the Lallemande camera is that it has to be processed and prepared several hours before it can be used, and it only remains usable for about a day. The vacuum system must be opened to retrieve the plates and the photocathode is consequently destroyed. Several modifications are under development in which the vacuum chamber is divided into a permanent high vacuum part containing the photocathode and a demountable part containing the plates. The two sections are linked by a thin, vacuum-tight mica window which is pervious to electrons. The photographic plates are pressed against the outside of the window, and it is not surprising that this leads to a serious loss of resolution.

(*b*) The simplest form of receptor is the type of phosphor screen found in all television receivers, and the simplest form of image converter is an evacuated tube having a photocathode at one end, a phosphor at the other and a magnetic or electrostatic field along the tube to accelerate and focus the electron image. The best phosphors available have efficiencies in the region of 20 per cent, and so this simple tube would have a relatively small gain. Each electron incident at the phosphor would produce a flash of light carrying 20 per cent of the energy of the incident electron. This would be in the form of a bunch of photons bigger than the bunch required to eject the electron from the photocathode, since the electron will have increased its energy at the expense of the accelerating field.

Although such a simple tube would be of little practical advantage, it is possible to produce a cascade process along these lines that does produce a useful gain.

Cascade intensifiers include amplifying elements which consist of thin mica sheets coated on one side with a phosphor and on the other side with a photocathode (Fig. 2). The close proximity of these surfaces, coupled with the presence of the focusing field,

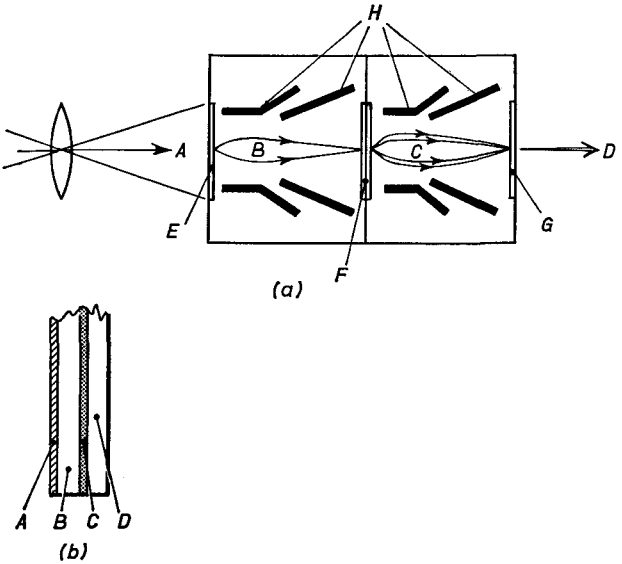


Fig. 2. A two stage Phosphor-photocathode Cascade Intensifier

(*a*) *A.* Incident light beam
B. Initial photo-electron beam
C. Intensified photo-electron beam
D. Output light beam
E. Photocathode layer
F. Intensifier screen
G. Aluminium backed phosphor layer
H. Electrostatic lenses

(*b*) *Section of Intensifier Screen*
A. Thin aluminium film
B. Phosphor
C. Thin mica support
D. Photocathode

ensures that there is very little loss of resolution as the energy transformation proceeds.

Electrons from the initial photocathode are accelerated and focused on to the screen phosphor. The phosphor emits many photons, several of which will eject electrons from the screen

photocathode. Each of these electrons will be accelerated and focused on to the final phosphor producing a flash of light. For 10,000 volt incident electrons the gain of such a screen is nearly 20, but for 25,000 volt electrons the gain is as high as 80. A two stage intensifier of this type will have sufficient gain to produce a visible flash of light for each primary electron from the first photocathode.

In practice it is found that the mica screen supports can be made about 5 microns thick, but in order to prevent optical interference or feed-back from the first phosphor on to the first photocathode it is necessary to cover the outer surface of the phosphor with an opaque evaporated layer of aluminium. This has the added advantage that it provides electrical conductivity for the phosphor, and can be used to prevent charge build up over the surface.

A variant of this cascade process is one involving the direct secondary emission of electrons from certain materials.

Support screens of electron-pervious materials, such as thin aluminium oxide, carrying thin conducting aluminium films as before, can hold extremely thin films of secondary emitting materials. These films are of the order of 0.05 micron in thickness, and are of semi-conducting materials such as potassium chloride or barium fluoride. Such materials have the property that when energetic electrons are incident on one side, many low-energy electrons are given off by the other side. For a 5,000 volt incident electron a potassium chloride layer will emit up to 7 secondaries.

For practical reasons, involving the difficulty of constructing such weak films on electron transparent supports which conform to accurate curves, these devices are only used with magnetic focusing fields. Commercially produced intensifiers of this pattern are available, having 5 stages and photon gains of more than 50,000.

The main disadvantage of this type is that, for increasing electron energies, high proportions of the primary electrons pass straight through the intensifier screens and only contribute to the background radiation from the final phosphor.

(*c*) Image converters involving the use of scanning techniques have the immense advantage that the viewing section may be remote from the detecting section and linked to it simply by a cable. All the other devices described must be operated on a single optical axis and, together with ancillary equipment, can become very heavy and inconvenient to move.

The main disadvantage of a television system is that the resolution is severely limited by the scanning frequency.

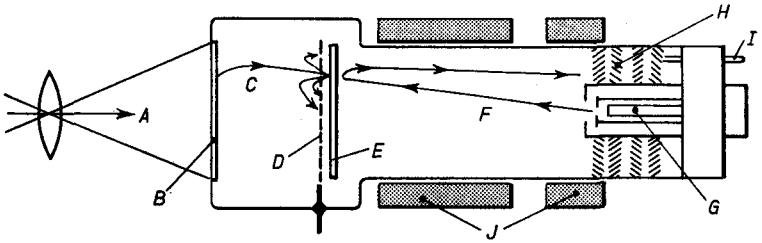


Fig. 3. Image Storage Tube (orthicon)

A. Incident light beam
B. Photocathode
C. Initial photo-electrons
D. Wire mesh collector
E. Thin glass target
F. Scanning electron beam
G. Electron gun
H. Electron multiplier to collect returning scanning beam
I. Video signal output
J. Scanning coils

For low light-level work the first stage of a storage tube of this type may contain cascade intensifiers, but the first photocathode and final electron image are obtained in the same way as for other devices. The electron image, however, is focused on to the front surface of a thin insulating glass plate which behaves as a charge storage unit (Fig. 3). Incident electrons cause the ejection of secondaries from the glass which are then collected by a fine wire mesh positioned just in front of the surface and maintained at a small collecting voltage. The glass target is then left with a charge

image on its front surface which, by induction, also appears on the back. In order to detect the charge image on the rear surface, the whole target is scanned by a narrow beam of low energy electrons which supplies sufficient negative charge to each part of the surface to re-create the initial state of uniform charge. The reflected scanning beam is then metered to estimate how much charge has been used in neutralizing the target, and in this way the video signal is generated. Once a modulated electrical current is obtained, it is a relatively simple task to display the image on the phosphor of a cathode ray tube.

For events of short duration, where high framing speeds are necessary, it is important that the charge images on the storage target should not overlap, and so the target resistance is chosen to be low enough for images to leak away in the appropriate time.

For astronomical work it is necessary to use very high resistance targets and to operate the tube in pulses as required. This allows the building up of intense charge images from weak sources and exposure or integration times may be several minutes in length.

(*d*) Solid state devices are mentioned only for completeness because, although nothing suitable for astronomical work has yet been developed, a large amount of research is being carried out in this direction.

The device would consist of a layer of photoconducting material brought into contact with a layer of electro-luminescent material (Fig. 4).

Photoconductors, such as cadmium sulphide or telluride, vary in electrical impedance depending on how strongly they are illuminated, whereas electro-luminescent materials, such as activated zinc sulphide, emit light when excited by an electric field.

If two such materials, separated by an anti-feedback layer, are excited by an alternating electric field, then the change in impedance of one layer could be made to control the electric field applied to the other layer. Such a system could form the basis of a converter of high efficiency but time will tell whether the practical difficulties involved will ever be solved.

This brief survey has been intended as an introduction to what

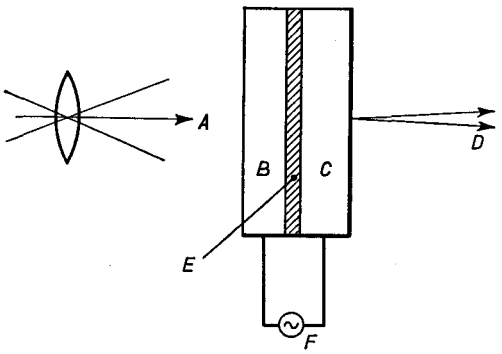


Fig. 4. Schematic Solid State Image Intensifier

A. Incident light beam
B. Photoconductor
C. Electro-Luminescent material
D. Amplified light beam
E. Opaque anti-feedback layer
F. Oscillating power supply

has already become an exciting new branch of observational astronomy. A Lallemande camera has been successfully operated for some time with the 120-inch reflecting telescope at the Lick Observatory, and image converters of various types are now being used in conjunction with the world's largest telescopes in the hunt for quasi-stellar objects.

A promising field of research would seem to be the study of faint short-period variable sources where the shortest available photographic exposures are much greater than the transient events being looked for. The much shorter exposures needed with the new intensifiers may bring a whole new range of phenomena within our grasp.

It would be surprising if the application of image intensifiers and converters to astronomical problems did not herald great advances in the study of the universe.

The Van Allen Radiation Belts

H. G. MILES

Although 1957 will always be remembered as the start of the space age, 1958 will go down in history for the discovery of possibly the most sensational geophysical phenomenon for many years. Since 1896, when Birkland investigated the motion of cathode rays in a magnetic field, many leading scientists including Poincaré, Størmer and Alfvén, postulated the idea of radiation being trapped in the Earth's magnetic field. Many theories were put forward to explain the aurora and geomagnetic storms, thought to be caused by these trapped particles. Rocket experiments in the early and middle fifties confirmed the presence of high electron densities in the upper atmosphere, with energies of the order of 10,000 electron volts. Singer studied the motion of low energy electrons and protons trapped in a magnetic field and suggested that this motion partly explained the ring current surrounding the Earth which had been advocated by Chapman. Towards the end of 1957, Christofilos put forward the idea that these trapped particles could be caused by the interaction of cosmic rays with the upper regions of the atmosphere. He proposed a series of high altitude atomic bomb explosions to test this theory. These took place towards the end of 1958, but the existence of the radiation belts had by this time been confirmed by the information received from the first few artificial satellites.

The first successful American satellite, Explorer 1, was launched on 1958 January 31 into a highly elliptical orbit (apogee 1,155 miles, perigee 217 miles). It was designed to count cosmic ray particles at various heights above the Earth's surface. At first everything appeared to be working correctly, with the count increasing with height. At a height of about 500 miles, especially

in the equatorial regions, the number appeared to drop suddenly to zero. At the time it was suspected that the Geiger counter was not functioning correctly. Unfortunately most of the information transmitted by Explorer 1 could not be received back to Earth, due to the fact that the satellite transmitted in real time, i.e. there was no method of storing the information on board the probe, and the counts were transmitted as soon as measured. These signals could only be received when the probe passed over or near to a receiving station. To overcome this, a tape recorder was placed aboard Explorer 3, launched on March 26, into an orbit which took it about 1,740 miles above the Earth's surface. The returns agreed completely with those of the earlier satellite. There was a gradual increase in the number of particles up to 300 miles, a much more rapid increase to just under 600 miles, and then it fell to zero. It was suggested that this fall to zero was due to the counter becoming saturated and not being able to function properly because it could not cope with such a high concentration of particles. Geiger counters were known to behave in such a manner; and on this conclusion, Professor J. Van Allen announced the existence of a belt of high energy electrons and protons surrounding the Earth at a height of 400 to 500 miles.

During the few days in which Sputnik 2 transmitted information (1957 November) high concentrations of particle radiation were noted but it was left to Sputnik 3, whose orbit took it to latitudes 65° north and south, to confirm the presence of the belt. From the data received, it was thought there were two regions or belts, one in the equatorial and the other in the auroral zones.

To overcome the saturation difficulty experienced in the earlier Explorer satellites, Explorer 4 was equipped with two counters, one of which was capable of recording high density radiation without becoming saturated and the other, a scintillation counter, capable of measuring the energies of the particles more than the actual number. It showed that the radiation count increased up to 1,400 miles (the apogee of the orbit at latitudes 50° north and south of the equator). The suspicion that the belt extended to greater heights was confirmed by the American deep space probes

Pioneer 1, 3 and 4 and the Soviet lunar probe Mechta (Lunik 1).

The results from Pioneer 1 (1958 October 11) showed that the belt appeared to have a maximum at a height of 10,000 miles. Pioneer 3 (launched 1958 December 6) clarified the suspicion of the possibility of there being two belts. On the outward journey to just under half the distance to the Moon and on its return, it recorded two peaks of radiation, one at a distance of 3,000 miles and the other at 10,000 miles. At distances greater than 10,000 miles the radiation intensity was found to decrease and was negligible at 40,000 miles.

Lunik 1 (launched 1959 January 2) confirmed the results of the Pioneers, but Pioneer 4 (launched 1959 March 3) reported a big increase in the intensity of the inner belt and an increase in distance of the peak of the outer belt. Whereas Lunik 1 and Pioneer 3 had been launched during periods of low solar activity, the launching of Pioneer 4 took place a few days after the occurrence of an intense solar flare.

Having found these belts, it was necessary to explain their presence in precise terms. Although it had been known for over fifty years that magnetic fields could trap charged particles, the existence of the belts came as a big surprise. In a magnetic field, a charged particle is subjected to a force which acts in a direction at right angles to both the direction of motion of the particle and the direction of the field. If the magnetic field is uniform (i.e. if the lines of force are parallel) the particle will travel in a spiral motion as shown in Fig. 1. If, however, the field is not uniform, the lines of force will not be parallel, and will converge in the direction of increasing field strength. The spiral will get smaller and the pitch angle, that is to say the angle at which the spiral

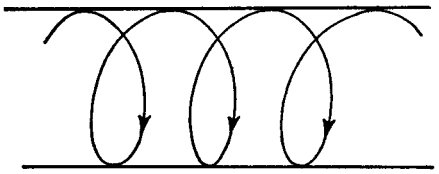


Fig. 1

advances, will also get smaller, as shown in Fig. 2. As the angle approaches zero, the magnetic field will cause the spiral to travel in the opposite direction. The particle will therefore travel in a path shown in Fig. 3. The point at which the path reverses is

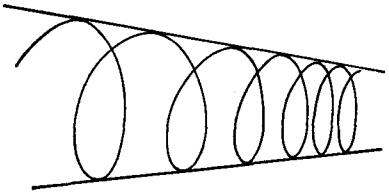


Fig. 2

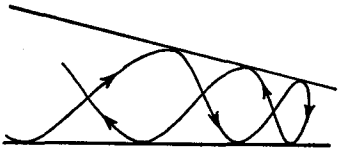


Fig. 3

called a magnetic mirror. If we consider the Earth's magnetic field, the lines of force are closer together in the polar regions than they are in the equatorial regions. Therefore the particle will become trapped, travelling backwards and forwards as shown in Fig. 4. The overall picture is of course three-dimensional, and the trapped radiation forms a ring round the Earth. In addition to the to-and-fro motion between the mirror points, there is a further

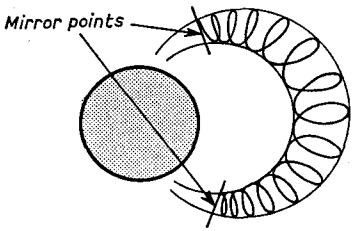


Fig. 4

motion caused by the decreasing strength of the magnetic field with increasing distance from the Earth. This causes the charged particle to drift round the Earth, the protons (positively charged) travelling in a westerly direction and the negatively charged electrons travelling in the opposite direction. This results in the formation of a doughnut-shaped region round the Earth, although this is only an approximation because the Earth's magnetic field is by no means regular. This drift of the positively and negatively charged particles in opposite directions is equivalent to the flow of an electric current – the so-called ring current. The strength of this current is normally relatively small, and has a negligible effect on the Earth's magnetic field. At times of solar flares, however, the density of the charged particles increases enormously, and hence the strength of the ring current increases. It is thought that this is responsible for the magnetic storms which occur suddenly.

The early observations indicated two distinct zones of radiation, now known as the inner and outer Van Allen zones. The inner zone appeared to contain high energy protons and the outer predominantly high energy electrons. Because the intensity of the fields did not vary in step, it was argued that the radiation originated in different ways. It appeared that the overall strength of the radiation in the inner belt remained fairly constant, but that of the outer belt could increase a thousandfold at times of a solar flare.

The high energy protons in the inner belt had energies in the region of 100 million electron volts. This was confirmed by sounding rockets and by photographic emulsions sent up by satellites. Later observations have shown that the energy of the protons lies within the range of 0·1 to 609 million electron volts, the number decreasing with increasing energy. The electrons existing in this zone have energies much less than 1 million electron volts.

It is thought that cosmic rays are responsible for the inner belt. These rays have very high energies, and consist of charged atomic nuclei (including protons). Because of their very high energies, they can pass through the Earth's magnetic field and collide

with the atomic particles in the upper atmosphere, forming neutrons and other particles. Since the neutron does not possess a charge, it can travel in any direction and not be influenced by the Earth's field. Those that travel away from the Earth are called albedo neutrons. These albedo neutrons will disintegrate into protons and electrons after a few minutes (the half-life is in the order of 15 minutes). The protons and electrons will of course be trapped by the Earth's magnetic field. Because the proton has roughly the same mass as a neutron, most of the energy is transfered to the proton and only a small amount to the electron. Hence the energy distribution of the protons will be similar to that of the incoming cosmic rays. This theory is capable of explaining the occurrence of protons up to a height of about 2,000 miles. The theory is unfortunately not completely satisfactory. It does not, for example, explain the electron component completely. Other processes must be present to account for these and also the low energy protons.

Because of the difference in behaviour of the inner and outer zones at times of solar activity, it is obvious that the mechanism for the formation of the outer zone must be different from that which causes the inner zone. The differences in intensity and distribution of the particles in the outer belt recorded by the earlier American and Russian space probes at times of varying solar activity have been confirmed by the satellites launched during the last few years.

It is therefore reasonable to assume that the electrons in this zone originally came from the solar wind and plasma. The actual mechanism is, however, not yet understood because of the difficulty in explaining why the electrons have such high energies. Explorer 12, launched on 1961 August 14, showed that the outer zone consisted of electrons with energies in excess of one or two million electron volts together with electrons and protons with considerably lower energies. If the zone is in temperature equilibrium, this would mean that energies of 1 million electron volts volts would imply a source at a temperature of 10,000 million degrees (10^{10}). The Sun could definitely not be the source of

electrons with such high energies. For example, the solar plasma associated with an average solar flare travels at about 1,000 miles per second, giving an energy for the electrons in the region of 7 electron volts. Energies of this order were confirmed by Pioneer 5 when it intercepted plasma from a flare when it was about 5 million miles from the Earth. The Geiger counter on board, designed to record energies larger than 20,000 electron volts, did not register any increase in the recording rate. The protons occurring in the outer zone are also of low energy, although by reason of their greater mass they would have energies nearly a thousand times that of the associated electrons. In addition, the outer zone would not be capable of holding high energy protons. The radius of the spiral path taken by these particles would be so large that it would bring them into the Earth's lower atmosphere and they would therefore escape from the trap. In general the radius of the loops of the electron paths is less than a few miles, but for protons the radius can be in the region of several thousand.

The link between solar activity and behaviour of the outer zone is quite close. Usually the number of high energy electrons drops soon after a geomagnetic storm is recorded and then increases to many thousand times greater than the original level. It then gradually falls over a period of several days. The actual process of capturing and giving them the greatly increased energy presents a great problem. Evidence collected from artificial satellites seems to indicate that the method of entry into the outer belt is via the tail of the Earth's magnetic field. The shape of the Earth's field is not regular. On the side nearest to the Sun, it is confined to a distance of about ten Earth radii, but on the side away from the Sun it has been found that it reaches out to very large distances. Up to 1964, it was thought that this distance was limited to about 50 Earth radii, but more recent work suggests distances of several astronomical units. (An astronomical unit is the distance of the Sun from the Earth.) The solar electrons can thus enter the Earth's field where its strength is weakest, i.e. in its tail. It is possible that the electrons are then accelerated by the distortion of the magnetic field caused by the solar plasma. However, much

more work has to be done before the problem is completely solved.

In 1960, Soviet scientists put forward the idea that there was a third radiation belt located at about 10 Earth radii. American workers, however, although admitting that there is sometimes an increase in radiation density in this region, claim that it lies beyond the Earth's magnetic field and therefore cannot be considered as part of the Earth's radiation belt.

Closely associated with solar flare activity is the aurora formed about 60 to 200 miles high in the atmosphere at latitudes in the region of 65 degrees. The auroral lights are formed by protons and electrons entering the atmosphere and electrically exciting the oxygen and nitrogen atoms present in those regions. It is thought that low energy plasma enters the outer zone as explained above, is accelerated by some process, and escapes into the atmosphere in the high latitudes. Electrons with energies of about 10,000 electron volts excite these atoms and cause the displays.

The idea of two separate zones has now been discarded, and the modern ideas tend to consider the Van Allen zones as a single radiation belt with a gradual change in properties as the distance from the Earth increases. But it is obvious that many more satellites and space probes will have to be launched before a complete and accurate picture of the phenomenon can be painted.

Quasi-Stellar Objects

E. M. LINDSAY

At the meeting of the American Astronomical Society of 1960 December 28–31, Allan Sandage reported that the strong radio source 3C 48 had been identified with a 16th magnitude star in Triangulum. Accompanying the star was a very faint wisp of nebulosity measuring 12″ × 5″. The spectrum of 3C 48, obtained by Greenstein, Munch and Sandage, was unlike that of any known star. Hydrogen was absent and apparently neutral Helium and ionized Helium, Calcium and Oxygen were present (1).

A possible explanation was that this was a distant galaxy; a more probable one that it was the remnant of a supernova. Apart from the Sun, radio sources had hitherto been identified with gaseous nebulæ in our own galaxy or the remnants of supernovæ or galaxies.

At the following meeting of the Society, 1961 June 18–21, Harlan Smith and Dorrit Hoffleit (2) had found no evidence of a supernova explosion from an examination of some 2,500 Harvard plates taken in the interval 1895–1952, no variation greater than ±0·2 mag since 1898 and no measurable proper motion. This of course did not exclude the possibility of 3C 48 being the remnant of some sort of nova-type explosion.

In 1963, Matthews and Sandage (3) identified two more strong radio sources, 3C 196 and 3C 286, with stellar-like objects. The Jodrell Bank radio observers (4) had failed to resolve 3C 48, giving it a radio diameter of $<1''$. For 3C 196, 75 per cent of the radio flux came from a halo of diameter 12″, the rest from an unresolved core $<1''$ diameter. For 3C 286, 40 per cent of the radio flux arose from a halo $\sim 20''$ in diameter, the rest from an unresolved core $<1''$ diameter. Direct photographs identified 3C

196 with an 18th magnitude star-like object and associated with this was a very faint wisp of nebulosity measuring 3″ × 1″. 3C 286 was identified with a 17th magnitude star-like object, but the observations were not sufficient to decide if any nebulosity were associated with it.

The spectra of these three sources were unusual and unlike one another. The main features of 3C 48 were broad emission lines at λλ 4686, 4580, 3832. There were faint emission lines in the red but H_α was absent. Spectra of 3C 196 obtained by Schmidt showed a continuum with no prominent features while 3C 286 showed λ 5170 in emission and possibly λ 4390 in absorption. Plates with an 11-year interval yielded no measurable proper motions. The colours of all three objects were unusual and were particularly rich in the ultra-violet. Photoelectric UBV observations of 3C 48 over a period of 13 months showed variation in light; the radio flux was apparently constant. If these objects belonged to the galaxy, Matthews and Sandage estimated a rough minimum distance of 100 parsecs and a mean absolute magnitude $M = +12$.

The most accurate determination yet of a radio source, 3C 273, was made in 1963 by Hazard, Mackey and Shimmins (5) by the lunar occultation method. The observations showed it to have two components separated by 19·5″. About 80 per cent of the radio flux came from a core 0·5″ wide of component B, the core being surrounded by a halo 7″ wide. Component A had a core 2″ wide surrounded by a 6″ diameter halo. They noted that the position of component B coincided closely with that of a 13th magnitude star. After the paper by Matthews and Sandage was written but before publication, Schmidt (6) confirmed this identification and found a faint nebulous wisp extending 11–20″ from the star and 1–2″ width. The spectrum of the star was not ordinary; the most outstanding features were broad emission bands at λλ 5632, 3239, 5792, 5032 in order of strength. Other weaker emission bands were present. The bands were not identifiable at these wavelengths, but by postulating a large redshift of $z = \Delta\lambda/\lambda_o = 0{\cdot}158$ (+47,400km/sec) the above emission bands corresponded to H_β (4861), MgII

(2798), the forbidden line of O III (5007) and H_γ (4340). Two weaker bands corresponded to H_δ and H_ε. Further work on the infra-red spectrum by Oke (7) identified λ 7590 with $H\alpha$ (6563).

In the same issue of *Nature*, Greenstein and Matthews (8) were able to identify the sharper features of 3C 48 with known lines of MgII, [NeIII], [NeV] and [O II] on the assumption of a redshift $z = 0{\cdot}3675$ (+110,200 km/sec). Other of the broad lines could possibly be hydrogen.

The absence of measurable proper motion, the width and strength of the forbidden lines relative to the permitted and the identification of the lines by assuming large redshifts combined to cast serious doubts on these objects being near by (~100 parsecs) extremely dense (radius ~10 km) stars in our Galaxy. A more likely explanation was that they were distant or parts of distant galaxies. With a Hubble constant of 100 km/sec per megaparsec, the distances of 3C 273 and 3C 48 would be 500 and 1,100 megaparsecs respectively.

That three more objects, 3C 9, 3C 216 and 3C 245, belonged to this class was confirmed by Ryle and Sandage (9) by utilizing their pronounced ultra-violet excess. A double exposure on a 103a–O plate with firstly a Schott GG 11 filter (λ 3,900 — λ 5,000) and secondly with a UG 2 filter (λ 3,200 — λ 3,900) showed a markedly brighter image in the ultra-violet. The name quasi-stellar radio source seems first to have been introduced by Schmidt and Matthews (10) in identifying 3C 47 and 3C 147 with two 18th magnitude stellar-like objects. The spectra were complex and could be explained by assigning redshifts of $z = 0{\cdot}425$ (+127,500 km/sec) to 3C 47 and $z = 0{\cdot}545$ (+163,500 km/sec) to 3C 147 with corresponding distances of 1,275 mpcs and 1,635 mpcs. It would appear that 75 per cent of the radio flux of 3C 47 came from a halo 2′ in diameter surrounding a 4″ diameter core (11) (4) or from two components separated by 70″. So also with alternative structure for 3C 147 (12); two components each <1″ with separation 2·4″ or an ellipse 1·9″ × <1″.

The list of quasars with lines identified, published by the end of 1965, is given in Table I. All spectra show a continuum. With

H, both permitted and forbidden ionized lines are present of the type found in planetary and diffuse nebulæ. The lines are considerably broadened, ranging from some 20 Å–100 Å. Not all quasars examined show spectral lines. Schmidt (14) reports three cases where they are absent and eight sources showing only a single emission line. It can be difficult of course to detect weak broad emission on a continuous spectrum due to lack of contrast. The most distant object listed in the Table is 3C 9 where the Lyα line (λ 1216) is shifted into the visible region (λ 3666). A question mark indicates that emission is almost certainly present at the indicated wave-length; a double question mark that emission may be present.

An explanation of the presence of the continuum with normal and highly ionized forbidden lines is not easy. The Greenstein-Schmidt (13) model, as an example, envisages the origin of the emission lines and radio emission from an extended filament area of a few parsecs diameter while the continuum and light variations arise from a core of some 10^9 $M_\odot$ of the order of 1 parsec in diameter. The variation of radio flux introduces a further problem in interpretation.

In column 7 the distances are in megaparsecs. There is naturally doubt what the true distances are since the formula used for computing these depends on the assumed world model. If we take $v = cz$ and $d = \frac{v}{H}$ where $H = 100$ km/sec per mpc we get velocities exceeding that of light for the highest two values. Velocities have here been computed from the formula

$$v^2 = cz\,(1 + z^2)^{-\frac{1}{2}}$$

The visual absolute magnitudes in column 8 are uncorrected for absorption in our galaxy and for redshift. Even without these corrections the objects are brighter than the brightest galaxies. If we apply corrections of 0·25 Cosec b m for absorption in the galaxy and a first order correction of 2·5 log (1 + z) for redshift effect we get a range from −22·8 to −26·5, the former being about the same absolute magnitude of a giant elliptical galaxy.

TABLE I

Quasars with Identified Spectral Lines

Source	*Spectral Lines*	*V*	*B-V*	*U-B*	*z*	*d*	M_v	*References*
3C 9	Lyα 1216, C IV 1550	18·21	0·23	−0·74	2·012	2686	−24	15; 9
47	MgII 2978, [NeV] 3426, [NeV] 3346?, [O II] 3727, [NeIII] 3869, [NeIII] 3968, H_γ 4340, [O III] 4363, H_β 4861??, [O III] 4959, 5007	18·1	0·05	−0·65	0·425	1173	−22	10; 16
48	MgII 2798, [NeV] 2975, [NeV] 3346, [NeV] 3426, [O II] 3727, [NeIII] 3868, H_γ 4340, HeII 4686, H_β 4861, [O III] 4959, 5007?	16·2	0·42	−0·58	0·367	1034	−24	8, 13, 17; 3, 18, 16
147	O III 3133, [NeV] 3426, [O II] 3727, [NeIII] 3869, [NeIII] 3968	17·8	0·65	−0·37	0·545	1435	−23	10; 16
245	C III 1909, [MgV] 2417??, [O II] 2470??, [MgVII] 2506??, [MgVII] 2626??, [MgV] 2783??, MgII 2798, MgII 2804, [A_rIV] 2854, [A_rIV] 2869, [MgV] 2928??, [NeV] 2974	17·25	0·45	−0·83	1·029	2150	−24	15, 19; 9, 16
254	C III 1909, MgII 2798, [NeV] 3426, [O II] 3727, [NeIII] 3869	17·98	0·15	−0·40	0·734	1739	−23	15; 20
3C 273	MgII 2798, HeII 3180?, [O II] 3727?, H_ϵ 3970, H_δ 4101, H_γ 4340, HeII 4686?, H_β 4861, [O III] 4959, 5007, H_γ 6563	12·8	0·21	−0·85	0·158	468	−26	6, 21, 13, 22; 18, 23, 24, 16
1252 + 11	[NeIV] 2424??, [O II] 2470??, [MgVII] 2506??, [MgVII] 2626??, MgII 2798, MgII 2804, [A_rIV] 2854?, [A_rIV] 2869, MgV 2932, [NeV] 2974??, O III 3133, HeII 3203??, [NeV] 3346??, [NeV] 3426??, [O II] 3727??	16·64	0·37	−0·75	0·870	1969	−25	19; 25
3C 279	MgII 2798, [A_rIV] 2854, 2869, [MgV] 2928, [NeV] 3346, [NeV] 3426, [O II] 3727, [NeIII] 3869, H_ζ 3889, [NeIII], H_ϵ 3968??, H_γ 4340?	17·75	0·26	−0·56	0·538	1422	−23	19, 16; 20
286	C III 1909 [NeIV] 2424??, MgII 2798, MgII 2804, [NeV] 3346, [NeV] 3426, [O II] 3727??	17·30	0·22	−0·84	0·849	1941	−24	27, 28, 29, 19; 16
3C 287	C IV 1550, C III 1909, MgII 2798	17·67	0·63	−0·65	1·055	2177	−24	15; 30
MSH 14–121	MgII 2798, O III 3133, [NeV] 3426	17·5?	—	—	0·938	2052	−24	31
3 C 334	[MgVII] 2506??, [MgVII] 2626??, MgII 2798, [A_rIV] 2854?, [A_rIV] 2869??, [MgV] 2928, [NeV] 2974, O III 3133, HeII 3204, [NeV] 3346??, [NeV] 3426?, [O II] 3727??, [NeIII] 3869?, [NeIII] H_ϵ 3968??, H_δ 4102, H_γ 4340, [O III] 4363	16·41	0·12	−0·79	0·555	1455	−24	19, 32; 20
345	MgII 2798, [A_rIV] 2854??, [A_rIV] 2869, [MgV] 2928?, [NeIV] 2974?, O III 3133??, HeII 3203, [NeV] 3346, [NeV] 3426, [O II] 3727??, [NeIII] 3869, [NeIII] H_ϵ 3968??, H_δ 4102, H_γ 4340, [O III] 4363??	16	—	—	0·595	1534	−25	19, 32; 30
351	MgII 2798??, [A_rIV] 2854, 2869??, O III 3133??, [NeV] 3346??, [NeV] 3426, [O II] 3727, [NeIII] 3869?, [NeIII], H_ϵ 3968??, H_γ 4340??, H_β 4860, [O III] 4959, 5007	—	—	—	0·371	1043	—	19
380	[MgVII] 2506??, [MgVII] 2626?, MgII 2798, [A_rIV] 2854, [A_rIV] 2869, [NeV] 3346??, [NeV] 3426, [O II] 3727?, [NeIII], 3869? [NeIII] H_ϵ 3968??, H_δ 4102?, H_γ 4340?	17	—	—	0·692	1707	−24	19, 32; 30
3C 446	Lyα or C IV 1216 or 1550, N IV or C III 1488 or 1509	18·39	0·44	−0·90	2·071 or 1·402	2728 or 2442	−24	32; 30
CTA 102	C III 1909, MgII 2798	17·32	0·42	−0·79	1·037	2159	—24	15; 30

3C 273 with $M_V = -26{\cdot}5$ is thus the brightest object so far found in the Universe. The mean value of M_V after corrections would be $M_V = -25{\cdot}0 \pm 0{\cdot}9$ (s.d.). The scatter about the mean is comparatively small but the sample is small, the corrections applied and the distances computed are uncertain. In the last column of Table I the references preceding the semi-colon give data on the spectra, those after on colours.

The available evidence points to small linear diameters for quasars. Since none is resolvable optically the radio values of the angular diameters are used. As mentioned above, 3C 48 has a diameter $<1''$, while for 3C 273 the stellar position agrees closely with that of the radio component B. Taking the linear diameter to be the angular diameter times distance would give linear diameters of about 5000 and 1100 parsecs respectively for 3C 48 and 3C 273. Using the formula (33)

$$y = \frac{cz\theta}{H(1+z)^2}$$

gives diameters of around 2600 and 900 parsecs.

The smallest angular diameter so far measured is that of CTA 102 which Palmer (34) gives as $<0{\cdot}10''$ or a linear diameter of less than 20 parsecs. He also infers that Component B of 3C 273 is itself double, each smaller than $0{\cdot}1''$ with separation $0{\cdot}4''$. That CTA 102 has a diameter $<0{\cdot}1''$ is confirmed by Adgie *et al.* (35) who also find that 3C 119, 3C 286, 3C 287 are $<0{\cdot}1''$ in at least one dimension. Further evidence for small diameters comes from the observations of scintillations of quasars by Hewish, Scott and Wills (36). They interpret such scintillations to be of interplanetary origin probably caused by the solar wind and they deduce diameters of the order of $0{\cdot}5''$. The scintillations of other small diameter radio sources is reported by Cohen (37) and that these are very strong when the sources are near the sun.

The redshift is here assumed to be cosmological. This has not been completely accepted. Arguments in favour of quasars being comparatively local, with distances of the order of 1–10 mpc, are given for example by Hoyle, Burbidge and Sargent (38).

Table II lists these objects accepted as quasars and published by the end of 1965, so far as I have been able to search the literature.

The positions (1950) are optical positions except for a few cases where no reference could be found and only radio positions published. The occultation method for determining radio positions, necessarily limited, gives the greatest accuracy, to about 1″. Other radio techniques give positions to about 2″ so that there is now little difficulty, from the positional error problem, in identification of radio and optical sources. In columns 4 and 5 the galactic coordinates are taken from Lund Annals 15, 1961. The references refer first to positions and secondly to magnitudes.

Variations in the magnitude of 3C 273 were measured by Smith and Hoffleit (49) on 600 Harvard plates taken between the years 1887–1963. The main features were a decline of 0·2 mag/-century, fluctuations in an approximate 10 year period, occasional flares up to 1 mag lasting about a week, the latter sometimes followed by a sharp drop in brightness. Variations from photographic plates were also found by Sharov and Efremov (50). Photoelectric observations in UBV light by Sandage (18) showed a decline of about 0·2 mag with fluctuations over a period of 10 months in 1963. Three observations on 3C 196 gave a rise of 0·24 mag in V while over a period of 4 years changes of up to 0·4 mag were measured for 3C 48, the light curves in U, V and B being in phase, indicating no change in colour. Changes of 0·2 mag in 3C 47 and 0·3 mag for 3C 216 have also been observed by Sandage. By comparison of original Palomar Sky Survey plates with more recent photographs larger changes have been found for 3C 43, a decrease in B of 0·9 mag 1954 September to 1965 June, and largest of all for 3C 2, an increase in B of 1·5 mag 1954 September to 1964 November (20). E. Margaret Burbidge and Rosenberg (26) also note that Sandage's value of V = 17·75 for 3C 279 is about 1 mag fainter than it appears on the Palomar Atlas Survey plates. Further evidence of variability of quasars is provided by Geyer (51) and by Goldsmith and Kinman (52).

The information on radio flux variation, for some time expected

TABLE II

List of Quasars

Source	*R.A.*	*Dec.*	*l*	*b*	*V*	*B-V*	*U-B*	*References*
	h m s	° ′						
3C 2	00 03 49	−00 21·1	99	−61	18·5	+1 :	—	20
3C 9	00 17 50	+15 24·3	112	−47	18·21	+0·23	−0·74	20, 9
0106+01	01 06 04	01 19·0	132	−61	18·39	0·15	−0·70	25
3C 43	01 27 15	23 22·9	134	−38	20 ?	—	—	20
47	01 33 40	20 42·3	137	−41	18·1	0·05	−0·65	10, 20, 16
48	01 34 50	32 54·3	134	−29	16·2	0·42	−0·58	39, 3, 18, 16
93	03 40 51	04 48·4	182	−38	18·1	0·34	−0·50	40, 30
119	04 29 08	41 32·1	161	− 4	—	—	—	20
138	05 18 17	16 35·4	187	−11	18·84	0·53	−0·16	20
147	05 38 44	49 49·7	161	+10	17·8	0·65	−0·37	39, 10, 16
181	07 25 20	14 43·8	203	15	18·92	0·43	−1·02	20
186	07 40 57	38 00·5	182	26	17·60	+0·45	−0·71	20
190	07 58 45	14 21·6	208	22	17·46	−0·20	−0·90	41, 16
191	08 02 04	10 24·0	212	21	18·4	+0·25	−0·84	20
196	08 09 59	48 22·1	172	33	17·6	0·60	−0·43	39, 3, 18, 16
204	08 33 18	65 24·1	151	36	18·21	0·55	−0·99	20
207	08 38 02	13 23·1	213	30	18·15	0·43	−0·42	20
208	08 50 23	14 04	214	33	17·42	0·34	−1·00	20, 30
212	08 55 56	+14 21·4	214	35	19·5	—	—	42
215	09 03 44	16 58·3	212	37	18·27	0·21	−0·66	20
216	09 06 17	43 06·0	179	43	18·3	0·50	−0·60	20, 9, 16
3C 217	09 05 55	38 04	185	43	18·50	0·25	−0·86	43, 16
0922+14	09 22 22	14 57·4	216	41	17·96	0·54	−0·52	25
0957+00	09 57 44	00 19·8	239	41	17·57	0·47	−0·71	25
3C 245	10 40 06	12 19·3	234	56	17·25	0·45	−0·83	42, 9, 16
247	10 56 09	43 17·6	171	62	18·82	+0·52	−0·25	20
249·1	11 00 31	77 15·1	130	39	15·72	−0·02	−0·77	44, 20
3C 254	11 11 56	40 54	172	66	17·98	+0·15	−0·49	39, 45, 20
1116+12	11 16 21	12 51·1	242	64	19·25	0·14	−0·76	25
3C 261	11 32 16	30 22·0	199	73	18·24	0·24	−0·56	20
263	11 37 09	66 04·4	134	50	16·32	0·18	−0·56	20
3C 268·2	11 58 27	31 50·5	187	78	18·31	0·42	−0·20	20
1217+02	12 17 38	02 20·3	285	64	16·53	0·02	−0·87	25
3C 270·1	12 18 04	33 59·8	166	81	18·61	0·19	−0·61	20
273	12 26 33	02 19·7	290	64	12·8	0·21	−0·85	5, 6, 42, 16
275·1	12 41 28	16 39·3	294	79	19·00	+0·23	−0·43	20
3C 277·1	12 50 15	56 50·6	123	60	17·93	−0·17	−0·78	20
1252+11	12 52 08	+11 57·3	306	75	16·64	+0·35	−0·75	25
3C 279	12 53 36	−05 31·2	305	57	17·75	+0·26	−0·56	20, 30
280·1	12 58 14	+40 25·3	115	77	19·44	−0·13	−0·70	44, 20, 16
281	13 05 23	06 58·3	316	69	17·02	+0·13	−0·59	20
287	13 28 16	25 24·6	23	81	17·67	0·63	−0·65	40, 30
3C 286	13 28 50	+30 46·0	56	81	17·30	0·22	−0·84	40, 3, 16
MSH 13–011	13 35 31	−06 12·0	323	55	17·68	0·14	−0·66	20, 30
3C 298	14 16 39	+06 41·7	352	61	16·79	0·33	−0·70	39, 45, 46, 20
3C 303	14 41 24	+52 14·3	91	58	—	—	—	*
MSH 14–121	14 53 13	−10 56·7	345	41	17	—	—	42, 47
3C 334	16 18 07	+17 43·5	33	41	16·41	+0·12	−0·79	46, 20
336	16 22 32	23 52·0	41	42	17·47	0·44	−0·79	20
345	16 41 18	39 54·2	64	41	16	—	—	40, 30
351	17 04 04	60 48·9	90	36	—	—	—	48, 19
380	18 28 13	48 42·7	77	+24	16·7	—	—	40, 30
403	19 49 43	02 22·2	42	−12	17·2	—	—	40, 30
432	21 20 26	16 51·8	68	−23	—	—	—	*
435	21 26 38	+07 19·8	61	−30	—	—	—	*
3C 446	22 23 11	−05 12·3	59	−49	18·39	0·44	−0·90	40, 30
CTA 102	22 30 08	+11 28·4	77	−39	17·32	0·42	−0·79	40, 30
3C 454	22 49 07	18 32·8	87	−36	—	—	—	*

* Quoted by Adgie and Gent (Nature *209*, 549, 1966) as quasi-stellar sources.

to be absent, is still meagre. At a wavelength of 32·5 centimetres, Sholomitskii (53) found for CTA 102 a sinusoidal period of 100 days with amplitude ± 23 per cent from observations on 9 days between 1964 August and 1965 February. This has been questioned by Maltby and Moffet (54) who found the radio flux to be constant within their limits of observational error between 1960 and 1961 August – admittedly before Sholomitskii's observations were made. Observations by Caswell and Wills (55) made only a few days from the predicted maximum and minimum of the 100-day period showed either a much smaller effect than that claimed by Sholomitskii or the absence of any. At a wavelength of 3·75 centimetres Dent (56) has found an increase of 40 per cent in the radio flux of 3C 273 over a period of 1000 days and a net decrease of 17 per cent and 19 per cent over a period of a year for 3C 279 and 3C 245 respectively. For 3C 273, measurements of the radio flux by Epstein (57) at 3·4 millimetres gave an increase by a factor of 3 (1965 April to July) while in an overlapping period (1965 January to June) Low (58) obtained a flux decrease by a factor of 10 at wavelength of 1 millimetre. Clearly much observational material has to be collected for quasars over as large a spectral range as possible.

A new type of object, the quasi-stellar galaxy, which is radio quiet but has a large redshift with the same spectral and colour properties of quasars was announced by Sandage (16). From an analysis of the Haro-Luyten (59) Catalogue of blue stars these 'interlopers' became more numerous at magnitudes fainter than $V = 14{\cdot}5$ so that most of the Haro-Luyten objects fainter than 16 were quasi-stellar galaxies. It has been pointed out by Zwicky (60) that the five objects individually described by Sandage belong to the subclass of blue compact galaxies previously described by him. More conservative estimates of the percentage of Haro-Luyten objects that may be non-galactic and very distant are given by Zwicky (ibid), Kinman (61) and Lynds and Villere (62).

Many more quasars will be found. Data on their spectra, colours, surface and spatial distribution, variation in flux at different wavelengths, absolute magnitude and dispersion in abso-

lute magnitude must be collected and interpreted. Their study is only in its initial stages.

REFERENCES

(1) *Sky and Telescope* XXI, 148, 1961.

(2) Harlan J. Smith and Dorrit Hoffleit, *A.J.* **66,** 295, 1961; *P.A.S.P.*, **73,** 292, 1961.

(3) Thomas A. Matthews, Allan R. Sandage, *Ap. J.*, **138,** 30, 1963.

(4) L. R. Allen, B. Anderson, R. G. Conway, H. P. Palmer, V. C. Reddish, B. Rowson, *M.N.*, **124,** 477, 1962.

(5) C. Hazard, M. B. Mackey, A. J. Shimmins, *Nature*, **197,** 1037, 1963.

(6) M. Schmidt, *Nature*, **197,** 1040, 1963.

(7) J. B. Oke, *Nature*, **197,** 1040, 1963.

(8) Jesse L. Greenstein, Thomas A. Matthews, *Nature*, **197,** 1041, 1963.

(9) M. Ryle, Allan Sandage, *Ap. J.*, **139,** 419, 1964.

(10) Maarten Schmidt, Thomas A. Matthews, *Ap. J.*, **139,** 781, 1964.

(11) P. Maltby, *Ap. J. Suppl.*, **7,** 124, 1962.

(12) B. Rowson, *M.N.*, **125,** 177, 1962.

(13) Jesse L. Greenstein, Maarten Schmidt, *Ap. J.*, **140,** 1, 1964.

(14) M. Schmidt, *Observatory*, **85,** 225, 1965.

(15) Maarten Schmidt, *Ap. J.*, **141,** 1295, 1965.

(16) Allan Sandage, *Ap. J.*, **141,** 1560, 1965.

(17) W. Kent Ford Jr., Vera C. Rubin, *Ap. J.*, **142,** 1303, 1965.

(18) Allan Sandage, *Ap. J.*, **139,** 416, 1964.

(19) C. R. Lynds, A. N. Stockton, W. C. Livingston, *Ap. J.*, **142,** 1667, 1965.

(20) Allan Sandage, Philippe Véron, John D. Wyndham, *Ap. J.*, **142,** 1307, 1965.

(21) J. B. Oke, *Nature*, **197,** 1040, 1963.

(22) J. B. Oke, *Ap. J.*, **141,** 6, 1965.

(23) Harold L. Johnson, *Ap. J.*, **139,** 1022, 1964.

(24) F. J. Low, H. L. Johnson, *Ap. J.*, **141,** 336, 1965.

(25) J. G. Bolton, Margaret E. Clarke, Allan Sandage, P. Véron, *Ap. J.*, **142,** 1289, 1965.

(26) E. Margaret Burbidge, Fred D. Rosenberg, *Ap. J.*, **142,** 1673, 1965.

(27) Maarten Schmidt, *Ap. J.*, **136,** 684, 1962.

(28) I. S. Shklovsky, *U.S.S.R. Astr. Circ.*, 250, 1963.

(29) J. B. Oke, *Ap. J.*, **142,** 1810, 1965.

(30) Allan Sandage, John D. Wyndham, *Ap. J.*, **141,** 328, 1965.

(31) E. Margaret Burbidge, *Ap. J.*, **142,** 1291, 1965.

(32) E. Margaret Burbidge, *Ap. J.*, **142,** 1674, 1965.

(33) Allan Sandage, *Ap. J.*, **133,** 355, 1961.

(34) H. P. Palmer, *Observatory*, **85**, 232, 1965.
(35) R. L. Adgie, H. Gent, O. B. Slee, A. D. Frost, H. P. Palmer, B. Rowson, *Nature*, **208**, 275, 1965.
(36) A. Hewish, P. F. Scott, D. Wills, *Nature*, **203**, 1214, 1964.
(37) Marshall H. Cohen, *Nature*, **208**, 277, 1965.
(38) F. Hoyle, G. R. Burbidge, W. L. Sargent, *Nature*, **209**, 751, 1966.
(39) Roger F. Griffin, *A.J.*, **68**, 421, 1963.
(40) P. Véron, *Ap. J.*, **141**, 332, 1965.
(41) Margaret E. Clarke, *M.N.*, **127**, 405, 1964.
(42) C. Hazard, M. B. Mackey, W. Nicholson, *Nature*, **202**, 227, 1964.
(43) A. S. Bennett, *Mem. R.A.S.*, **68**, 163, 1961.
(44) M. S. Longair, *M.N.*, **129**, 419, 1965.
(45) R. L. Adgie, *Nature*, **204**, 1028, 1964.
(46) J. D. Wyndham, *A.J.*, **70**, 384, 1965.
(47) P. Véron, *Ap. J.*, **141**, 1284, 1965.
(48) R. L. Adgie, H. Gent, *Nature*, **209**, 549, 1966.
(49) Harlan J. Smith, Dorrit Hoffleit, *A.J.*, **68**, 292, 1963; *Nature*, **198**, 650, 1963.
(50) A. S. Sharov, Y. N. Efremov, *Russ. A.J.*, **40**, 950, 1963.
(51) E. H. Geyer, *zf. Ap.*, **60**, 112, 1964.
(52) D. W. Goldsmith, T. D. Kinman, *Ap. J.*, **142**, 1693, 1965.
(53) G. B. Sholomitskii, *Inform. Bull. on Var. Stars Comm.*, 27 I.A.U. No. 83, 1965; *Soviet Astronomy A.J.*, **9**, 576, 1965.
(54) P. Maltby, A. T. Moffet, *Ap. J.*, **142**, 409, 1965.
(55) J. L. Caswell, D. Wills, *Nature*, **206**, 1241, 1965.
(56) W. A. Dent, *Science*, **148**, 1458, 1965.
(57) Eugene E. Epstein, *Ap. J.*, **142**, 1285, 1965.
(58) F. J. Low, *Ap. J.*, **142**, 1287, 1965.
(59) G. Haro, W. J. Luyten, *Bull. Obs. Tonantzintla*, **3**, 37, 1962.
(60) F. Zwicky, *Ap. J.*, **142**, 1293, 1965.
(61) T. D. Kinman, *Ap. J.*, **142**, 1241, 1965.
(62) C. R. Lynds, G. Villere, *Ap. J.*, **142**, 1296, 1965.

Recent Advances in Astronomy

PATRICK MOORE

Twenty years ago, practical space-research was still regarded as something of a joke in official scientific circles. The idea of sending a manned rocket to the Moon was apt to be greeted with a derisive snort and a caustic reference to science fiction. Nowadays the pendulum has swung right over, and it is impossible to distinguish developments in astronomy from those in astronautics. Each year brings its own quota of surprises, and in this respect 1965 and the first half of 1966 were particularly fruitful. To make the situation clear, it must be stressed that these words are being written in mid-July 1966; the *Yearbook* is due to be published well before Christmas, and printing takes time, so that it is impossible to be completely up to date. Previously this would not have mattered in the least, but at present the march of events is so swift that the point should certainly be made. I do not for a moment believe that a man will land on the Moon between July and December; nevertheless, let us admit that it could conceivably happen. And we shall almost certainly have new lunar and planetary probes.

First, however, something may be said about two recent events which are not directly connected with astronautics: the Great Comet of 1965, and the 1966 annular eclipse of the Sun.

Great comets have been depressingly rare in recent years, and there has been a complete dearth of them since 1910. Of course, Halley's Comet appeared then, and may be confidently expected back again in 1986; but 1910 also saw the visit of the Daylight Comet, which was a good deal brighter than Halley's, but must be classed as non-periodical in view of the fact that its revolution time must amount to many centuries. There have been numbers of naked-eye comets since, and a few, notably Arend-Roland of spring 1957, became quite prominent; but a comet of this sort is

very different from a brilliant object with a long tail stretching across the sky. Consequently, there was considerable excitement when calculations showed that a comet discovered telescopically by two Japanese amateurs, Ikeya and Seki, gave every prospect of becoming spectacular in October 1965. The probable magnitude was given as in the region of −10, in which case the comet would be visible in broad daylight, and a tail would inevitably add to its glory.

In some parts of the world, Ikeya-Seki did indeed live up to expectations, and that it must be classed as a Great Comet is unquestionable. Fine naked-eye views were obtained from some regions of North America, Australia and Africa, and splendid photographs were taken. Unfortunately Ikeya-Seki's period of glory was brief, and from Europe the comet was a sad anti-climax. From Britain it never became a prominent naked-eye object, and the many people who wakened early in the hope of seeing it were disappointed. (Personally, I even went to the length of making a pre-dawn aircraft flight in order to avoid the clouds; a Royal Air Force crew very kindly took me up in a Shackleton, together with H. H. R. Grossie of the Armagh Observatory, and we cruised fruitlessly over Ireland for some hours without catching even a fleeting glimpse of the comet.) A slightly bizarre note was introduced by the Television service, which showed a photograph taken in all good faith by a Surrey amateur – ostensibly recording the comet, but actually producing nothing more than an interesting cloud effect!

However, the outlook is not too depressing. Ikeya-Seki was a 'sun-grazer'; that is to say, at its closest point to the Sun (perihelion) it passed remarkably close to the solar surface. Moreover, it seemed to be one of a series. There may be more to come, and it is quite likely that we shall see a more co-operative Great Comet in the foreseeable future.

On the same theme, mention must be made of the meteorite which landed in Leicestershire on Christmas Eve, 1965; it is known as the Barwell Meteorite, from the village in which the main fragments were collected. It seems that before breaking up

in the atmosphere during descent, the meteorite must have weighed about 200 pounds, which is a British record. Its fall was seen by many observers, despite the prevailing cloudy conditions, and a painstaking investigation by H. G. Miles proved that there were at least three "fireballs", no doubt fragments of a single original object. Many pieces were found – I even found one myself in a field just outside Barwell; it weighed 1¼ pounds, and had made a small pit in the soil. The meteorite was of the stony variety, and showed all the usual characteristics of its kind. Nobody was injured by the fall, but a fragment fell through a factory roof, while another piece entered a house via the window and was subsequently found nestling in a vase of artificial flowers.

The solar eclipse of May 20 1966 was partial in Britain, with over 40 per cent of the Sun hidden from Greenwich and over 30 per cent from Armagh. It was well seen, and provided an interesting spectacle, though not an important one. From the region of the Greek islands it was annular, and enterprising members of the Junior Astronomical Society who went to Lesbos obtained a first-class film of it, showing a spectacular Baily's Beads. Professionals concentrated upon rocket work, in an attempt to gauge the effects of the eclipse on the Earth's ionosphere.

So far as the Moon is concerned, the most important developments in the early part of 1966 were the soft landings of rocket probes, first Russia's Luna 9 and then the American Surveyor I. The Russians had had several previous failures, but Luna 9 proved to be a real triumph. It came down in the Oceanus Procellarum (Ocean of Storms), and sent back some magnificent photographs taken from the actual surface. The general effect was very similar to that of a lava-field, and it was clear that the whole Moon is a decidedly rough world. Surveyor I, which followed in June, was equally successful; it too landed in the Oceanus Procellarum, and more than 10,000 high-quality photographs were received. The probe even survived its first lunar night, and was re-activated when the Sun rose once more over that area of the Oceanus Procellarum. The experiment was finally terminated by deliberate intent rather than by a fading-out of the signals.

It is tempting to compare the Luna 9 results with those from Surveyor I. I do not propose to do so; I will content myself by repeating that both were outstanding achievements. More actual information is available from United States than from Soviet sources, but it is clear that the two experiments lead to much the same conclusions. And first, it is now certain that the idea of a Moon covered with soft dust can be rejected. In 1954 T. Gold, then of the Royal Greenwich Observatory, had suggested that the Moon's seas were in fact dust-oceans; he even wrote that a spacecraft would sink into the dust with all its gear. The suggestion was not well received by practical lunar observers, because it did not fit the observational data, but close attention was paid to it by the space-planners. Reassuringly, Luna 9 and Surveyor I did not sink into dust; they came down on a hard surface, and there is now no reason to doubt that from this point of view manned landings are practicable, though there may well be unsafe areas here and there. From all accounts, the legs of Surveyor I sank into the Moon by only about three-quarters of an inch, even though the landing took place at 10 feet per second. Other experiments, too, indicate a virtual absence of dust, though there is plenty of rocky débris.

The experiments did not finally solve the question of the origin of the lunar formations, and this particular argument continues as strongly as ever. However, it may be appropriate to mention another line of research which depends not upon rockets, but upon 'old-fashioned' observations from Earth. Since 1958, when the Russian astronomer N. A. Kozirev detected a reddish glow in the lunar crater Alphonsus, various other transient phenomena have been reported – in the Aristarchus area, for instance, by James Greenacre and his colleagues at the Lowell Observatory in Arizona. Statistical research, carried out mainly by Barbara Middlehurst and her associates at the University of Arizona, has indicated that phenomena of this sort really are due to mild vulcanism. Not all authorities agree with this conclusion, and in any case the vulcanism is on a very small scale; but it may nevertheless be very significant.

Studies have been made by means of what are termed 'Moon-Blink' instruments, which depend upon observing the Moon by means of red and blue filters alternately – so that a reddish patch will show up as a blinking spot. Considerable success has been obtained by American Moon-Blink teams, and in April 1966 the team organized by the Lunar Section of the British Astronomical Association, using Moon-Blinks made on a rather simpler pattern, were able to detect a distinct reddish 'event' in the majestic crater Gassendi. The original discovery was made by P. K. Sartory, and was confirmed independently by various other members of the Lunar Section team (including myself; using the 10 in. refractor at Armagh Observatory, together with T. J. C. A. Moseley, I found the redness quite clear). The causes of these phenomena are still open to question, but at least the reality of the phenomena themselves now seems to be beyond reasonable doubt.

Meanwhile, the date for the first manned lunar landing has been put variously at 1970, 1969 or even 1968. Which – if any – of these dates is correct remains to be seen; we cannot discount the possibility of some unexpected hazard which will delay all plans for going to the Moon, and put the date forward again by years or even decades. Yet if all goes well, the first astronaut to land on the Moon should set foot on the lunar surface in the reasonably near future. Before these words appear in print, much extra information may be to hand.

The Moon is our first target in space, because it is so close. Next on the list are the two nearest planets, Mars and Venus. Mars was badly placed in the twelve months preceding July 1966, but new probes may be dispatched to it before Christmas; the planet comes to opposition in 1967 (details are, of course, given in the monthly notes). If Venus is as unpleasantly hot as the Mariner II results indicate, then Mars becomes the first extra-lunar astronautical objective more or less as a matter of course.

It cannot be said that the results of the first successful Mars probe, Mariner IV, have been reassuring. In addition to discovering the craters, fully described in Dr Fielder's article in this *Yearbook*, Mariner indicated that the planet's atmosphere is even

thinner than had been previously thought. With every new development, the prospects of advanced life there seem to recede further and further into the distance. Most authorities still consider that living organisms provide the most likely explanation of the famous dark patches, but this view is not universally held, and in 1966 a new hypothesis was put forward by Joseph Otterman and Finn E. Bronner, of Pennsylvania. On this theory, the dark areas are due to frost phenomena.

Otterman and Bronner drew attention to the production of what may be termed microhills, raised by the formation of needle ice – as seen in, for instance, Pennsylvania in certain areas of wet soils after freezing nights. Typically, these microhills are very rough columns, from a few millimetres to a few centimetres in height. They cause a definite darkening effect in soils of low reflecting power, and this is the main point of the Otterman-Bronner theory. It is held that early in the Martian spring, the polar cap begins to sublimate (that is to say, pass directly from the solid to the gaseous state). The water vapour released into the atmosphere is carried toward the equator, but each afternoon or evening, as the temperature falls sharply, water is deposited in the upper few millimetres of soil, freezing as the temperature falls still more, and expanding to produce microhills. When the temperature rises again next day, the ice sublimates, and the progress toward the equator continues. The famous 'wave of darkening' from pole to equator would thus take place in a series of jumps – a course of events impossible to verify from Earth. The microhills thus formed would persist until reduced by erosion, caused by Martian winds. The fact that the reddish-ochre 'deserts' are not affected is put down to differences in soil characteristics.

Up to now, all non-organic theories of the Martian dark areas have been subject to criticism on various grounds. For instance, Svante Arrhenius believed the dark regions to be due to hygroscopic salts, which picked up moisture from the shrinking polar cap and darkened in the process; but Kuiper has shown that the caps would not contain enough moisture for the process to operate. This may also be a weak point in the new frost theory,

but it is too early to say, and in any case the idea is worthy of careful consideration. Probably the whole question of 'life on Mars' will remain open until space-research methods provide a final answer.

Venus has been the subject of considerable attention, and two Russian probes were dispatched to it, arriving in early 1966. The two vehicles were designed to undertake many investigations – one of which, presumably, was to confirm or deny the 1962 Mariner II reports of a surface temperature in the region of +800 degrees Fahrenheit, which would make manned landings there somewhat difficult. Unfortunately, the familiar Soviet weakness in long-range communication again proved to be a stumbling-block. From Russian reports, one of the Venus probes passed close to the planet and the other actually landed there, but contact was lost before the critical period, so that neither vehicle can be regarded as a success.

There was some adverse criticism about the actual landing, on the grounds that contamination might be introduced to Venus. This is a definite risk. There is virtually no chance that Venus is the abode of intelligent life, but the chances of lowly organisms cannot be ruled out; and it cannot be denied that whether Venus is lifeless or not, the introduction of Earth contamination would be scientifically disastrous. Of course, the Russians sterilized the probe as effectively as they could, but no sterilization process can be infallible. The main trouble is to decide just what can be done about the problem as a whole. Whether 100 per cent sterilization can ever be achieved remains to be seen; the critics argued that it would have been wiser to wait until improved methods have been developed, and the point is certainly a valid one, though there is something to be said on both sides. Little can be added as yet, since the Russians lost touch with the probe before its final descent, and we do not know exactly what happened to it.

Mercury, the innermost of the planets, is out of our present rocket range, but it too has been studied. There now seems strong evidence that the 'day' amounts to about 58 Earth-days, so that Mercury does not have a captured rotation, as had been previously

thought. If so, then there will be no zone of permanent day, no area of everlasting night, and no intermediate Twilight Zone; all parts of Mercury will be in sunlight at one time or another. Astronautically, the question is of academic interest only, since Mercury is totally inhospitable, but astronomically the whole matter is of obvious importance.

In this brief review, it may be said – and with justice – that too much space has been devoted to the Solar System, and too little to the greater universe. My excuse is that much of the current programme in astrophysics is bound up with those fascinating objects, the quasars; and quasars are reviewed at length by Dr Lindsay in his article on page 139. Moreover, no spectacular novæ have appeared of late, and ordinary stellar researches can be carried out only at major observatories.

Yet one discovery cannot be omitted – that of a pair of pygmy stars, of a new kind. The discovery is due to W. Luyten, and concerns the binary known as LO 101 15/16. It has an annual proper motion of 1″·62, and a probable distance of not more than 19 light-years, so that it is one of our nearest stellar neighbours. Luyten has found that one component, with a photographic magnitude of 15·8, is white; its spectrum is more or less featureless, apart from very wide hydrogen lines seen in absorption. The width of the lines, and the red shift (presumably an Einstein effect) suggests that the star is smaller than the Moon, and is much fainter and denser than a typical White Dwarf. The other member of the pair is very red; its photographic magnitude is 15·3, and it may possibly be an S-type dwarf lying 2½ magnitudes below the Main Sequence. The revolution period of the pair must be of the order of 2,000 years.

Previously there have been no known cases of binaries in which one component is blue-white, one is very red, and both are pygmies. (Incidentally, the combined mass of the two members of LO 101 15/16 is thought to be about equal to the mass of the Sun.) It is not yet possible to see how significant this discovery may be, but it underlines the fact that our knowledge of the various types of stars is still very far from complete.

In the widest field, one further aspect should be mentioned here. This concerns the origin of (or, more accurately, the development of) the universe.

For more than a decade there has been a conflict between the evolutionary theory (according to which the galaxies were produced from material created at one set moment) and the steady-state theory (whose supporters hold that the universe has always existed, and will exist for ever). The question was excessively difficult to tackle, and the last word has seemed to lie with radio astronomy; radio waves can be detected over distances greater than those accessible optically. Now, at last, it has become clear that the steady-state theory fails its vital tests, and it has been more or less abandoned. This does not automatically justify the 'big bang' model, and the idea of an oscillating universe is coming more and more into favour; but at least definite progress has been made.

Quasars may hold the key. As Dr Lindsay has stated in his article, there have been recent suggestions that the red shifts in their spectra do not indicate a tremendous distance, and if this is so, then our whole idea of the make-up of the universe may have to be revised. If the red shifts in the spectra of the quasars are not cosmological, than can we be sure that the same is not true of ordinary remote galaxies? It is not impossible that the picture of galaxies in mutual recession may have to be given up, which will create a cosmological revolution indeed.

At the moment, there are not many authorities who consider that so drastic an alteration will be needed, but we have to admit that cosmology is in a state of flux, so that we can do no more than await the results of future work. At least nobody can claim that present-day astronomy is a static science!

PART THREE

For Stellar Observers

There are signs that more and more amateur astronomers are starting to concentrate upon aspects of stellar work. There is indeed a great deal to be done – mainly, perhaps, in the field of variable star observation, since work here can be carried out with modest equipment provided that the user is both practised and skilful. This year's 'cycle', again provided by James Muirden, deals with some prominent variable stars, and will, it is hoped, be found helpful to those whose interests lie beyond the Solar System.

For less experienced observers, some notes have been given on some of the highly-coloured stars visible with the naked eye or with binoculars. And lists of convenient double stars and nebular objects have also been added. Since the Greek alphabet has to be used on the maps, it is probably as well to repeat it here for those who do not have last year's issue of the *Yearbook*. The letters are as follows:

α Alpha	ϵ Epsilon	ι Iota	ν Nu	ρ Rho	ϕ Phi
β Beta	ζ Zeta	κ Kappa	ξ Xi	σ Sigma	χ Chi
γ Gamma	η Eta	λ Lambda	o Omicron	τ Tau	ψ Psi
δ Delta	θ Theta	μ Mu	π Pi	υ Upsilon	ω Omega

Coloured Stars

To the casual observer, all stars look white. A very few – notably Betelgeux in Orion and Antares in Scorpio – have a reddish hue, but not many people will notice the colour unless they deliberately look for it. Yet in fact there are very marked differences in hue, as it evident when binoculars or telescopes are used.

The Sun, of course, is yellow. One would expect a white star to have a hotter surface, while a red star will be cooler; and this is in fact the case. The Sun's surface temperature is some 6,000°C. Sirius, which is almost pure white, attains more than 10,000°, while Betelgeux must be content with a modest 3,400°. Very recently, some extremely red stars have been studied whose surface temperatures seem to be below 1,000°. At the other end of the scale, the curious greenish-white 'Wolf-Rayet' stars exceed 35,000°.

The temperature of a star has a marked effect upon its spectrum. It is probably true to say that to the modern astronomer, the spectroscope is more important than the telescope (though it must be remembered that a stellar spectroscope would not be of much use without a powerful telescope to collect the light in the first place). The stars are divided into various special types, denoted by letters of the alphabet. These are as follows:

Types W, O and B: bluish-white, very hot indeed.
Type A: white, such as Sirius.
Types F and G: yellow. The Sun and Capella belong to type G.
Type K: orange. Arcturus is the best example.
Types M, R, N and S: various degrees of red. Betelgeux and Antares are of type M.

The chaotic sequence of letters was due to original errors in interpretation, so that, for instance, the old Types C and D were

found to be unnecessary. It should be noted, too, that most of the stars – certainly the vast majority of those visible with the naked eye – belong to types B, A, F, G, K and M. Of the rest, the very hot W and O stars are extremely rare, while the red R, N and S stars are too remote and therefore too faint to be seen without optical aid.

There are many bright naked-eye stars which are virtually pure white. One good example is Sirius, which, with its magnitude of −1·4, is much the most brilliant star in the whole sky. Its eminence is due not to its real luminosity, which is 'only' twenty-six times as great as that of the Sun, but to its relative nearness; it is a mere 8½ light-years away. There is no true colour in Sirius, but when low down in the sky – as it always is, as seen from Britain or the northern United States – it seems to flash red, blue and green. This is an effect due entirely to the Earth's atmosphere, and has nothing directly to do with Sirius itself. All bright stars twinkle and flash violently when low down, but Sirius' great brilliance makes the scintillation particularly obvious.

The only first-magnitude star which is of a decidedly bluish cast is Vega, which is almost directly overhead during evenings in summer. Seen through binoculars or a low-power telescope, it is a glorious sight. On the other hand, Capella, which occupies the overhead position during winter evenings, is markedly yellow. This means that Capella (spectrum G) is less hot at its surface than Vega (spectrum A). To compensate for this, Capella has a greater diameter, and is three times more luminous than Vega; it would take 150 Suns to equal Capella. Incidentally, Capella is an extremely close binary.

Only one naked-eye star is said to have a perceptibly greenish hue. This is Beta Libræ, of magnitude 2·6 and spectrum B8 (that is to say, intermediate between B and A). The colour is not at all conspicuous, and many people will fail to see it at all, but it has been described many times in the past. Of course, optical aid is necessary. To the naked eye Beta Libræ appears white.

There is a lesson to be learned here. Faint hues vanish where the light-intensity is low, which is why telescopes or binoculars

are needed to bring out the colours of the stars well. As an example, consider Betelgeux in Orion, magnitude 1 (though definitely variable), and Mu Geminorum, in the constellation of the Twins. The magnitude of Mu Geminorum is 2·9, but it, like Betelgeux, is of spectrum M – and it is just as red. Yet to the naked eye the colour of Betelgeux is quite obvious, while Mu Geminorum looks to all intents and purposes white. Observe with a telescope, and the ruddiness of Mu is evident at once.

Another instance may be found in the northernmost constellation, Ursa Minor (the Little Bear). The Pole Star is of spectrum F, so that it is slightly yellowish, though most people will call it white. The only other bright star in the constellation is Kocab, or Beta Ursæ Minoris, which is almost exactly of the same magnitude as the Pole Star. Telescopically, Kocab's orange colour comes out strongly. Its spectrum is K4, and it is more than 100 light-years away from us.

Probably the reddest of all the really bright stars is Antares, in Scorpio, which may be seen low down in the south during summer evenings. Its name means 'the Rival of Mars', and certainly Antares is a superb spectacle in a telescope, particularly as it has a faint companion which appears greenish (partly, let it be said, from the effect of contrast). Antares is a huge Red Giant, well over 200 million miles in diameter. Like all of its kind, it is extremely rarefied in its outer layers. Similar, though fainter in the sky, is Alpha Herculis; here too there is a greenish companion star. Other stars with a strong red colour are Alphard or Alpha Hydræ, Aldebaran in Taurus, and Beta Pegasi in the famous Square of Pegasus. Much less conspicuous is Mu Cephei, not far from the north celestial pole. It also is a Red Giant, but it is very remote, so that even at its brightest it never rises much above the fourth magnitude; it is an irregular variable of the same type as Betelgeux. The naked eye observer will notice nothing strange about it, but seen in a telescope it has been compared with a glowing coal, and Sir William Herschel aptly nicknamed it 'the Garnet Star'.

Red stars are divided into two well-marked classes, giants and

dwarfs. All the naked-eye stars which show a reddish tinge are giants, because the dwarfs are relatively feeble, and do not show up brilliantly even when close on the astronomical scale. Proxima Centauri, the nearest star beyond the Solar System, is a Red Dwarf; it is only just over four light-years away, but even so it is far too dim to be seen without a telescope.

In the earlier days of stellar research, great importance was placed in observing the different hues of the stars, and before the first world war the British Astronomical Association had a flourishing Star Colour Section. Things are different today; spectroscopic methods have taken over, and looking at the stars and estimating their colours is no longer of scientific importance. Yet it is a fascinating pastime, and the observer who cares to take a telescope or a pair of good binoculars, and turns his gaze to one star after another, will find much to interest him. It is totally untrue to claim, as so many beginners do, that all stars look white.

A Cycle of Variable Stars

JAMES MUIRDEN

Variable stars form one of the most important observational fields open to the amateur astronomer. These are stars which appear to vary in brightness, and this effect may occur for one of two reasons. First of all, we have the *eclipsing* type, where a binary pair is revolving in an orbit edge-on to the Earth. With first one star, and then the other, being periodically occulted by its partner, the total light seems to fluctuate up and down accordingly. Eclipsing binaries are so close that no telescope can actually show the separate stars, although astronomers can calculate their natures with reasonable accuracy.

More numerous are the intrinsic variables. Here, the star really does brighten and fade. Some intrinsic variables have predictable behaviour, following definite cycles of activity. Two well-known classes of these *regular* variables are the Cepheid and RR Lyræ stars. Then we have other stars which admit to a general law of behaviour, but exhibit individual and unpredictable variations on this pattern; these are known as *semi-regular* or *long-period* variables, since their periods are usually of the order of months. Finally, there are the *irregular* variables, which are quite unpredictable. It is in the observation of the semi-regular and irregular stars that the amateur can play so useful a part, for these are not closely studied at professional observatories.

The following notes deal with the brighter variables observable from British latitudes during the four seasons of the year. They all reach naked-eye visibility at maximum, and many can be observed with the naked eye or binoculars throughout their cycles. A more extensive list is included in that standby of every amateur: *Norton's Star Atlas*, which also indicates the

positions of the fainter ones more accurately than is possible here.

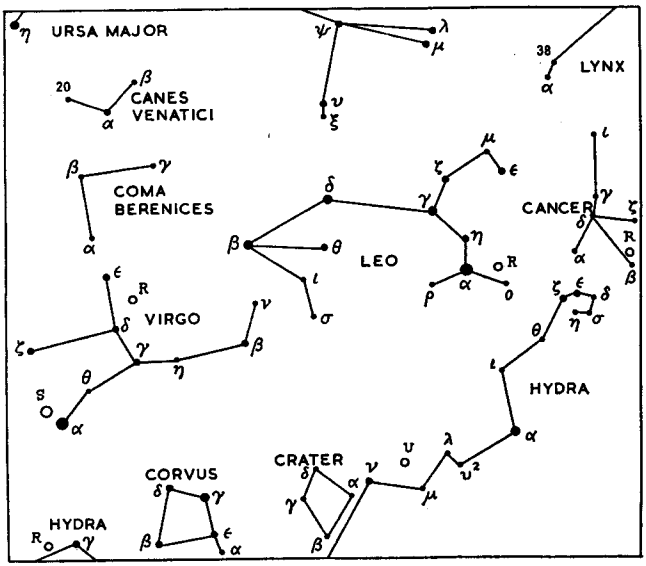
SPRING

Let us start our cycle with the small constellation of Corona Borealis (Map II), in which lies one of the most remarkable objects in the sky: the star T, just south of Epsilon. In May 1866, the British amateur J. Birmingham was amazed to find that a new 2nd-magnitude star had appeared in the group overnight, rivalling Alpha; but in just a few weeks it had sunk back once more to an inconspicuous star of the 9th magnitude. This remarkable performance earned it the nickname of the 'Blaze Star'; and in February 1946 it suddenly rose again, this time to the 3rd magnitude, sinking quickly back to its original brightness and remaining quiescent until the present time. Clearly, this is a star with surprises in store.

The variable R, 2 degrees north of Delta, is equally interesting. For most of the time it appears of the 6th magnitude, but after a period of months or even years it rapidly drops by 5 or 6 magnitudes, usually remaining at minimum for up to several months before rsing again. A number of variables behave in a similar manner, and they are referred to as R Coronæ Borealis stars.

The neighbouring constellation of Boötes (Map I) contains two variables very near Epsilon: R and W. R is semi-regular, with a period of about 220 days and a magnitude range from about 6 to 13; W (also known as 34 Boötis) is irregular, and fluctuates from 5·2 to 6·1. Estimates against near-by stars can be made with binoculars, although the 2nd-magnitude Epsilon is inconveniently close.

Virgo (Map I) possesses semi-regulars R and S, both of which can reach the 6th magnitude at maximum and fall to the 12th at minimum; the periods are about 145 and 372 days respectively, although it must be emphasized that quoted periods are only averages, and may vary greatly from one cycle to the next. R Leonis (Map I), which lies a little to the west of Alpha, is interesting for its intense red tint. Most semi-regulars are reddish, but R Leonis is exceptionally deep, and this colour is best seen



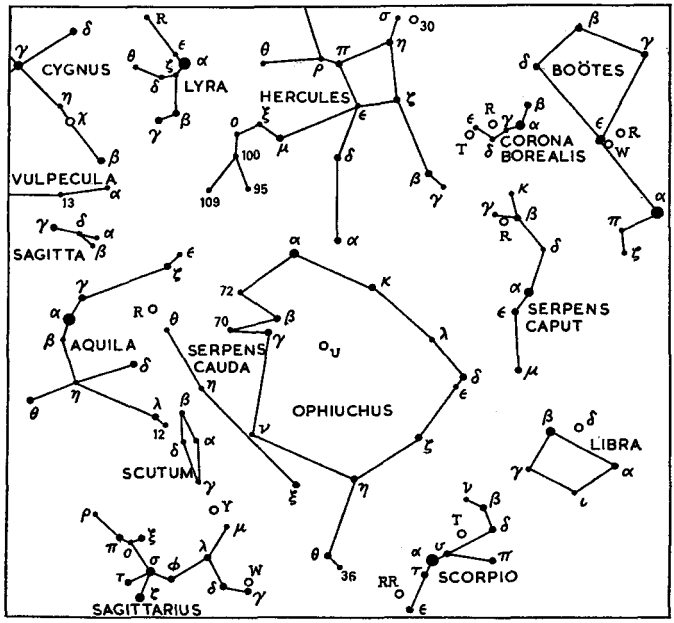
Map I

around the time of maximum, when it can reach the 6th magnitude. The minimum is about 10·5, the period about 312 days.

R Cancri (Map I) lies in a rather barren patch of sky 2½ degrees north of Beta, and is not hard to pick up at maximum (6·0–11·3, 362 days). The rambling constellation of Hydra (Map I) contains two variables which become quite bright at maximum: U, which forms a triangle with Nu and Mu, varies from 4·5 to 6·0 in an irregular manner, and R, 2½ degrees east of Gamma, can reach the 4th magnitude, fading to the 10th at minimum with a period of about 415 days.

SUMMER

Alpha Herculis (Map II) is one of the brighter examples of an irregular variable. It is a fine orange star, lying a little to the west of the 2nd-magnitude Alpha Ophiuchi, and it varies from about 3·1 to 3·9. It is, in addition, a fine double star with a greenish



Map II

companion. There is also the star 30, near Sigma, which shows variations from 4·7 to 6·0, again quite random.

U Ophiuchi (Map II) belongs to another class altogether. It is an eclipsing variable, known as an Algolid (after the prototype of its class, Algol), and it consists of two stars, one of which is much brighter than the other and so provides most of the luminosity. The dimmer component serves merely to eclipse it at regular intervals, the period being 1 day 16¾ hours, the magnitude varying from 5·7 to 6·7.

In the head of Serpens (Map II), conveniently placed between Beta and Gamma, is the semi-regular variable R (5·5–13·4, 357 days). To the south, in Libra, are two bright variables. Delta itself is an Algolid, ranging from 4·8 to 6·2 in a period of 2 days

8 hours, while Iota is irregular, oscillating between 4·3 and 5·0. In Scorpio (Map II), the variable RR (5·6–11·3, 279 days) is rather low for British observers, with a declination of $-30\frac{1}{2}$ degrees, lying near the cluster M.62. In the splendid cluster M.80, which lies near the fine red star Antares (Alpha Scorpii), is the curious variable T which, in imitation of its spectacular namesake in Corona Borealis, shot up to the 7th magnitude in 1860 May, faded in a month, and has shown no sign of activity since!

Down in Sagittarius (Map II) there are two conspicuous Cepheids. W has a period of 7 days $14\frac{1}{4}$ hours, and varies from 4·8 to 5·8; it is easily found, a degree north of Gamma. Y, near the globular cluster M.24, varies from 5·4 to 6·5 and has a period of 5 days $18\frac{1}{2}$ hours. It is interesting to note how Cepheids and similar stars are much whiter than those of long period.

The fine Milky Way constellation of Aquila (Map II) is made distinctive by its bright leader Altair. The variable R is of the semi-regular type (5·8–12·0, 310 days), while Eta is a bright Cepheid (3·7–4·5, 7 days $4\frac{1}{4}$ hours). Lyra (Map II), lit up by the brilliant Vega, is smaller but no less striking. R is a bright semi-regular variable (4·0–4·7) with the unusually short period of $46\frac{1}{2}$ days, while Beta, with a period of 12 days 22 hours, is the prototype of the Lyrid eclipsing variables. Unlike the Algolid or 'dark-eclipsing' kind, where the components are of very unequal luminosity, Lyrid variables are roughly comparable in brightness, so that two noticeable dimmings occur, when each of the stars is occulted by the other. In this particular case, the maximum magnitude is 3·4, while the minima are alternately 3·8 and 4·1.

Cygnus (Maps II and III) is another splendid constellation; its familiar cruciform shape has earned it the nickname of the Northern Cross, and since it lies in a dense region of the Milky Way it is replete with variables. Three are worthy of special mention. T, closely north-east of Epsilon, is irregular, with a magnitude range from 5·5 to 6·0; W, closely south-east of Rho, varies from about 5·0 to 7·6 with a period of about 131 days. Of far greater range is the star Chi, which can reach magnitude 4·2 at maximum, but sinks to the 14th magnitude at minimum,

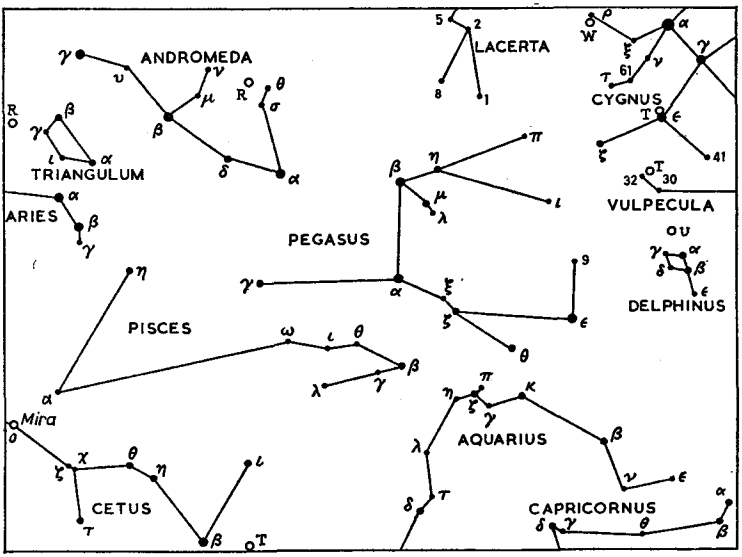
requiring a telescope of about 10 inches aperture for its observation. During its cycle of approximately 409 days it changes its luminosity by some 6,000 times, making the Sun appear refreshingly stable by comparison!

Two small asterisms east of Cygnus each contain a fairly conspicuous variable. Delphinus (Map III), a tiny but distinctive group, has the star U (6·4–7·3, irregular) north of Gamma, and in the more obscure Vulpecula (Maps II and III) we find the variable T, not far from the red star 32. This is a Cepheid, and its fluctuations from 5·2 to 6·4 can be followed very easily with binoculars by reference to its neighbour. The period is 4 days 10½ hours.

AUTUMN

The lengthening nights and incipient mists of autumn are associated in the astronomer's mind with the constellations Andromeda, Pegasus, Perseus, and their companions. Less noticeable, but nevertheless important for containing the most famous variable star in the sky, is Cetus (Maps III and IV), a dull-looking patch of sky below Pisces. When Bayer was drawing up his famous star-catalogue of 1603, he noticed a bright star in the head of the Whale and marked it as Omicron, without realizing that it was actually a variable star that happened to be at maximum magnitude at the time. Another observer of the same period, David Fabricius, also saw it, and later Phocylides Holwarda realized that the star brightened and faded with some consistency. At that epoch, no other star was known to show such extraordinary caprices, and it is hardly surprising that it was chistened Mira, which means 'The Wonderful'.

Mira, which can be picked up at maximum by passing a line from Alpha Ceti through Delta, is a semi-regular variable with a period which may be anything from 10 to 11 months (331 days on average). Its maximum and minimum brightness is also very variable; it has been known to reach the 2nd magnitude, while at other times it has only reached the 5th; and the minimum can be anything from 8·5 to 9·6. The amateur, even if he has only a



Map III

pair of binoculars, can do valuable work in following its rise and fall around the time of maximum. Another bright variable in the constellation is the star T (5·1–7·0, irregular), which lies about 5 degrees west of Beta.

The prominent constellation of Pegasus (Map III) contains strangely little of interest to the amateur, but there are two bright stars worthy of investigation. Beta is an irregular variable, ranging from 2·4 to 2·9, though it has a very rough period of about 35 days; and Epsilon, of magnitude 2·5, has been suspected of variability.

Andromeda (Map III), which lies to the north-east of the Great Square of Pegasus, contains one of the reddest variables in the northern sky. This is R, which lies near Theta, and its tint, when viewed through a large telescope, has been likened to that of a glowing cigarette-end. It must, of course, be remembered that colour estimates are reliable only when the star falls into a certain

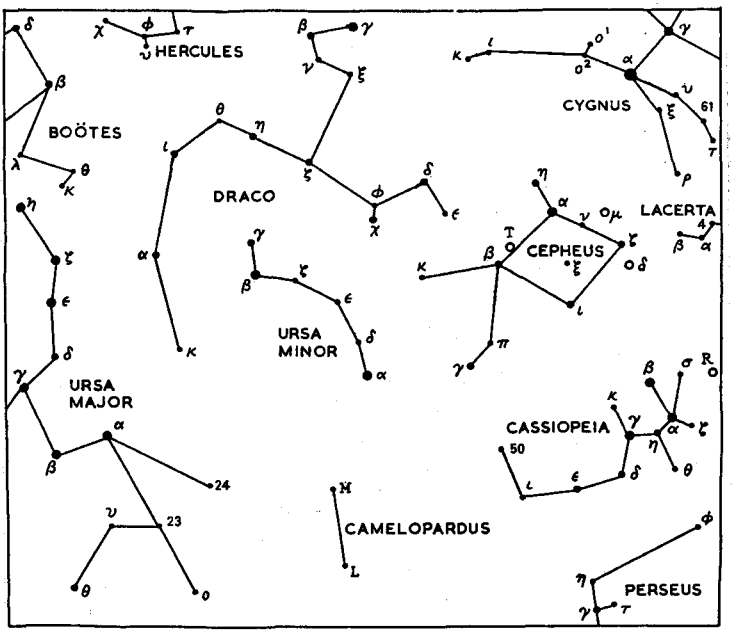
magnitude range; if it is too bright, the glare of the image masks the finer hues, and if it is too faint the eye cannot perceive colour at all. In the case of a 3-inch refractor, stars of between the 5th and 7th magnitudes reveal their tints to the best advantage. With a small telescope, therefore, colour estimates of most long-period variables can be made only near the time of maximum.

The small group of Triangulum (Map III) lying south of Gamma Andromedæ, contains the variable R, which fluctuates between 5·8 and 12·0 with a rough period of 270 days. In Perseus (Map V) there is the prototype of the Algolids, Beta, a dark-eclipsing variable with a period of 2 days 21 hours and a magnitude range from 2·3 to 3·5. It spends most of its time at maximum, the eclipse of the bright component lasting only 10 hours, during which time it falls to its minimum brightness and rises again. The B.A.A. *Handbook* gives predictions for this star, so that it is easy to choose a suitable evening for the observation of its fluctuations. The near-by Rho is a bright irregular variable, varying from 3·3 to 4·1.

Cassiopeia (Map IV), distinctively W-shaped, is associated with Perseus in lying in a splendid region of the Milky Way, and it contains two most interesting naked-eye variables. Alpha oscillates between magnitudes 2·2 and 2·6 with no definite period, while Gamma is usually of the 3rd magnitude but has been observed to brighten to above the 2nd, so that it shines as brightly as the Pole Star. These are worthwhile stars for the amateur to add to his list, since weekly estimates can be made in a few minutes without interfering with other observational programmes. The variable R occasionally reaches naked-eye visibility (5·3–12, 432 days).

Cepheus (Map IV) is another far northern constellation of interest to the variable star observer. Here we find the famous Delta (3·6–4·3, 5 days 9 hours), prototype of the Cepheids. Like most stars of its class, the rise, taking $1\frac{1}{2}$ days, is more rapid than the subsequent fall.

The star Mu is also of great interest. This shines with a beautiful port-wine colour (Hereschel referred to it as the Garnet Star), and the tint can be seen well with binoculars. It is an irregular

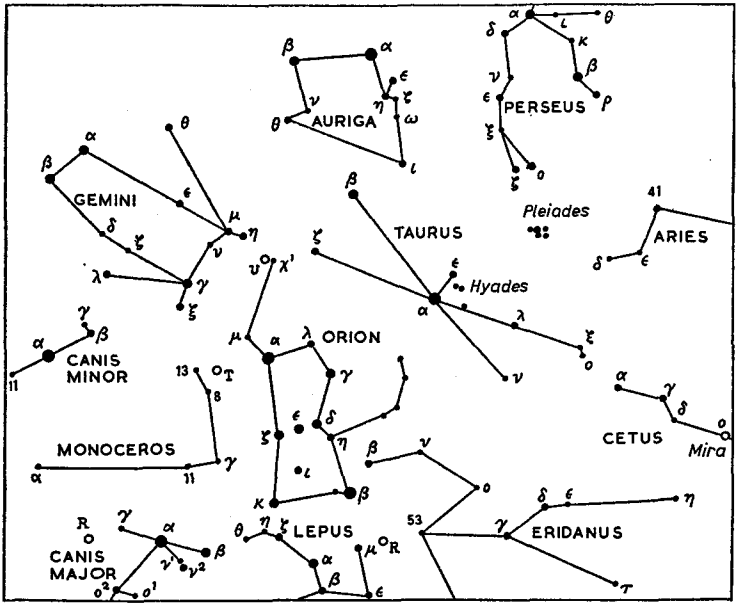


Map IV

variable, but never faint, since the range is only 3·7 to 4·7. T Cephei, south-west of Beta, is visible with the naked eye at maximum (5·5–9·5, 391 days).

WINTER

Orion (Map V) is the gem of the winter sky, and Alpha (Betelgeux) is a splendid red star which has been seen to outshine Beta or Rigel (0·1), while at other times it has sunk as low as 1·1. There is a very rough period of 5 years, but there are large fluctuations and one can never tell what Betelgeux may do next. Sometimes it is quiescent for months on end, while at others it can lose or gain half a magnitude in a matter of weeks. Another variable, U (5·4–12·3, 374 days), is not difficult to pick up when near



Map V

maximum, since it lies very close to Chi[1]. This was discovered by the Rev. T. W. Webb, a famous amateur astronomer of the last century who wrote an invaluable book called *Celestial Objects for Common Telescopes*. This lists a great many objects suitable for amateur observation, and is still useful despite its age; until recently it was hard to come by, but it has recently been reprinted by Dover Books and is now easily available.

Taurus (Map V) contains a bright Algolid; this is Lambda (3·3–4·2, 3 days 21½ hours), while Epsilon Aurigæ (Map V) is another bright eclipsing variable with a period of 27 years, the longest known for this kind of star. The period of a binary system increases with the distance of the components, so that the stars composing Epsilon Aurigæ must be very far apart by binary standards; even so, the system is so far away that we have no hope

of detecting the individual components. The variation of brightness is from 3·3 to 4·1.

Gemini (Map V) offers the variable star observer a minor mystery. It was the habit of Bayer, who devised the system of Greek lettering for the brighter stars, to apply the letters to each constellation in approximate order of magnitude, Alpha being the brightest, Beta the next brightest, and so on. Yet in the case of Gemini we find Alpha (Castor) to be appreciably inferior to Beta (Pollux) in magnitude. Can it be that one of the stars has brightened or faded during the $3\frac{1}{2}$ centuries since Bayer's time? Whether or not this is the case, there are at any rate two other, conspicuous variables in the group. Zeta is a Cepheid (3·7–4·3, 10 days 5 hours); and Eta is semi-regular (3·2–4·2, 231 days) with a fine red tint. In the same region of the sky is the Cepheid variable T Monocerotis (5·8–6·8, 27 days), and, farther south, the Algolid R Canis Majoris (5·9–6·7), with a period of only $27\frac{1}{4}$ hours.

To finish the cycle, we should take a look at one of the reddest stars in the sky. It lies in the constellation Lepus (Map V), and was first noticed by the amateur J. R. Hind in 1845, when he wrote of the variable R as being 'of the most intense crimson, resembling a blood-drop on the black ground of the sky; as regards depth of colour, no other stars visible in these latitudes could be compared with it'. The variation of R Leporis, the Crimson Star, is from 6·0 to 10·4, the period about 430 days, and it owes its redness in part to its relative coolness, the surface temperature being only 2,500°C.

The variables mentioned in this article are only the more obvious of the thousands that are within the range of the amateur observer. Many need apertures of the order of 12 inches for adequate observation, but by no means all; and there are nothing like enough observers to cover even the more interesting ones. The fascination of the semi-regular and irregular variables lies in their unpredictability, and consistent observations are essential if advances are to be made in our knowledge – knowledge which, in many cases, depends entirely on the work of a small band of amateurs.

Some Interesting Double Stars

The pairs listed below are well-known objects, and all the primaries are easily visible with the naked eye, so that right ascensions and declinations are not given. Most can be seen with a 3-inch refractor, and all with a 4-inch under good conditions, while quite a number can be separated with smaller telescopes, and a few (such as Alpha Capricorni) with the naked eye. Yet other pairs, such as Mizar-Alcor in Ursa Major and Theta Tauri in the Hyades, are regarded as too wide to be regarded as bona-fide doubles!

Name	*Magnitudes*	*Separation,"*	*Position angle, deg.*	*Remarks*
Gamma Andromedæ	3·0, 5·0	9	060	Yellow, blue. B is again double (0".4) but needs a larger telescope.
Zeta Aquarii	4·4, 4·6	2·6	291	Becoming more difficult.
Gamma Arietis	4·2, 4·4	8	000	Very easy.
Theta Aurigæ	2·7, 7·2	3	330	Stiff test for 3 in. OG.
Delta Boötis	3·2, 7·4	105	079	Fixed.
Epsilon Boötis	3·0, 6·3	2·8	340	Yellow, blue. Fine pair.
Kappa Boötis	5·1, 7·2	13	237	Easy.
Zeta Cancri	5·6, 6·1	5·6	082	
Iota Cancri	4·4, 6·5	31	307	Easy. Yellow, blue.
Alpha Canum Venat.	3·2, 5·7	20	228	Yellowish, bluish. Easy.
Alpha Capricorni	3·2, 4·2	376	291	Naked-eye pair. Alpha[2] again double.
Eta Cassiopeiæ	3·7, 7·4	11	298	Creamy, bluish. Easy.
Beta Cephei	3·3, 8·0	14	250	
Delta Cephei	var, 7·5	41	192	Very easy.
Xi Cephei	4·7, 6·5	8	270	Reasonably easy.
Gamma Ceti	3·7, 6·2	3	300	Not too easy.
Zeta Coronæ Borealis	4·0, 4·9	6·3	304	
Delta Corvi	3·0, 8·5	24	212	
Beta Cygni	3·0, 5·3	35	055	Yellow, green. Glorious.
61 Cygni	5·3, 5·9	25	150	
Gamma Delphini	4·0, 5·0	10	265	Yellow, greenish. Easy.
Nu Draconis	4·6, 4·6	62	312	Naked-eye pair.
Alpha Geminorum	2·0, 2·8	2	151	Castor. Becoming easier.
Delta Geminorum	3·2, 8·2	6·5	120	
Alpha Herculis	var, 6·1	4·5	110	Red, green.
Delta Herculis	3·0, 7·5	11	208	Optical double.
Zeta Herculis	3·0, 6·5	1·4	300	Fine, rapid binary.
Gamma Leonis	2·6, 3·8	4·3	121	Binary; period 400 years.
Alpha Lyræ	0·0, 10·5	60	180	Vega. Optical; B faint.
Epsilon Lyræ	4·6, 6·3	3	005	Quadruple. Both pairs
	4·9, 5·2	2·3	111	separable in 3 in. OG.
Zeta Lyræ	4·2, 5·5	44	150	Fixed. Easy double.
Beta Orionis	0·1, 6·7	9·5	205	Rigel. Can be split with 3 in.
Iota Orionis	3·2, 7·3	11	140	
Theta Orionis	6·0, 7·0			The famous Trapezium in
	7·5, 8,0			M.42.
Sigma Orionis	4·0, 7·0	11·1	236	Quadruple. D is rather
	7·5, 10·0	12·9	085	faint in small apertures.
Zeta Orionis	1·9, 5·0	3	160	
Eta Persei	4·0, 8·5	8·5	300	Yellow, bluish
Alpha Piscium	4·3, 5·3	1·9	291	
Alpha Scorpii	0·9, 6·8	3	275	Antares. Red, green.

Name	*Magnitudes*	*Separation,"*	*Position angle, deg.*	*Remarks*
Nu Scorpii	4 2,·6·5	42	336	
Theta Serpentis	4·1, 4·1	23	103	Very easy.
Alpha Tauri	0·8, 11·2	130	032	Aldebaran. Wide, but B is very faint in small telescopes.
Zeta Ursæ Majoris	2·3, 4·2	14·5	150	Mizar. Very easy. Naked-eye pair with Alcor .
Alpha Ursæ Minoris	2·0, 9·0	18·3	217	Polaris. Can be seen with 3 in.
Gamma Virginis	3·6, 3·7	4·8	305	Binary; period 180 yrs. Closing.
Theta Virginis	4·0, 9·0	7	340	Not too easy.

Some Interesting Clusters and Nebulæ

Object	R.A. *h*	*m*	Dec. °	′	*Remarks*
M.31 Andromedæ	00	40·7	+41	05	Great Galaxy, visible to naked eye.
H.VIII 78 Cassiopeiæ	00	41·3	+61	36	Fine cluster, between Gamma and Kappa Cassiopeiæ.
M.33 Trianguli	01	31·8	+30	28	Spiral. Difficult with small apertures.
H.VI 33–4 Persei	02	18·3	+56	59	Double cluster; Sword-handle.
M.1 Tauri	05	32·3	+22	00	Crab Nebula, near Zeta Tauri.
M.42 Orionis	05	33·4	—05	24	Great Nebula. Contains the famous Trapezium, Theta Orionis.
M.35 Geminorum	06	06·5	+24	21	Open cluster near Eta Geminorum.
H.VII 2 Monocerotis	06	30·7	+04	53	Open cluster, just visible to naked eye.
M.41 Canis Majoris	06	45·5	—20	42	Open cluster, just visible to naked eye.
M.44 Cancri	08	38	+20	07	Præsepe. Open cluster near Delta Cancri. Visible to naked eye.
M.97 Ursæ Majoris	11	12·6	+55	13	Owl Nebula, diameter 3′. Planetary.
M.3 Canum Venaticorum	13	40·6	+28	34	Bright globular.
M.80 Scorpionis	16	14·9	—22	53	Globular, between Antares and Beta Scorpionis.
M.4 Scorpionis	16	21·5	—26	26	Open cluster close to Antares.
M.13 Herculis	16	40	+36	31	Globular. Just visible to naked eye.
M.92 Herculis	17	16·1	+43	11	Globular. Between Iota and Eta Herculis.
M.7 Scorpionis	17	51·6	—34	48	Fine open cluster. Very low in England.
M.23 Sagittarii	17	54·8	—19	01	Open cluster nearly 50′ in diameter.
H.VI 37 Draconis	17	58·6	+66	38	Bright planetary.
M.8 Sagittarii	18	01·4	—24	23	Lagoon Nebula. Gaseous. Just visible with naked eye.
NGC 6572 Ophiuchi	18	10·9	+06	50	Bright planetary, between Beta Ophiuchi and Zeta Aquilæ.
M.17 Sagittarii	18	18·8	—16	12	Omega Nebula. Gaseous. Large and bright.
M.11 Scuti	18	49·0	—06	19	Wild Duck. Bright open cluster.
M.57 Lyræ	18	52·6	+32	59	Ring Nebula. Brightest of planetaries.
M.27 Vulpeculæ	19	58·1	+22	37	Dumb-bell Nebula, near Gamma Sagittæ.
H.IV 1 Aquarii	21	02·1	—11	31	Bright planetary near Nu Aquarii.
M.15 Pegasi	21	28·3	+12	01	Bright globular, near Epsilon Pegasi.
M.39 Cygni	21	31·0	+48	17	Open cluster between Deneb and Alpha Lacertæ. Well seen with low powers.

PART FOUR

Miscellaneous

Astronomical Societies

The advantage of joining an astronomical society are obvious enough. Full information about national and local Societies was given in the 1966 *Yearbook*; a condensed list, suitably brought up to date, is given below.

Name	*Secretarial Address*	*Yearly Subscription* § = members under 18, or 'juniors'	*Meeting Time and Place*
British Astronomical Association	303 Bath Road, Hounslow West, Middlesex (Miss Lydia A. Brown)	45*s* (§30*s*)	Burlington House, Piccadilly Last Wed. each month (Oct–June)
Irish Astronomical Society:			
Belfast Centre	35 Ardenvohr Road, Belfast (D. Beesley)	20*s* (§10*s*)	Fortnightly. Queen's University, Belfast
Dublin Centre	St Fintan's Cottage, Carrickbrack Road, Sutton, County Dublin (F. Murphy)	20*s* (§10*s*)	Fortnightly University College, Earlsfield Terrace, Dublin
Armagh Centre	The Royal School, Armagh (J. Perrott)	20*s* (§5*s*)	Monthly The Planetarium, Armagh
Junior Astronomical Society	44 Cedar Way, Basingstoke, Hampshire (E. W. Turner)	15*s*	Caxton Hall, London, S.W.1 Quarterly
Altrincham and District Astronomical Society	33 Edale Grove, Sale, Cheshire (F. W. Talbot)	5*s*	Park Road Library, Timperly 3rd Friday of each month
Aylesbury Astronomical Society	9 Elm Close, Butler's Cross, Aylesbury (N. Neale)	20*s*	As arranged
Birmingham Astronomy Group	17 Hannafore Road, Edgbaston, (W. E. Marsh)	20*s* (§5*s*)	Birmingham and Midland Institute Monthly
Bristol Astronomical Society	12 Lambley Road, Bristol 5 (S. J. Williams)	20*s*	Lecture Theatre, Bristol University 3rd Friday each month, Sept–May
Caithness and Dounreay Astronomical Society	Room 31, Ormlie Lodge, Thurso, Scotland (Miss M. J. A. Clark)	20*s*	Fortnightly
Cambrian Astronomical Society	57 Park Avenue, Whitchurch, Cardiff (R. W. Skelly and W. H. Sutherland)	15*s* (§7*s* 6*d*)	Fortnightly, Friday evenings, Oct.–June, in Cardiff
Cambridge Astronomical Society	5 Haggis Gap, Fulbourn (S. R. Whistler)	21*s* (§7*s* 6*d*)	7 Brooklands Avenue, Cambridge 2nd Mon. each month, Oct.–July
Chester Society of Natural Science, Literature and Art	8 Guy Lane, Waverton, nr. Chester (Mrs N. Hoskyns)	—	Grosvenor Museum, Chester Fortnightly
Chesterfield Astronomical Society	10 George Street, Brimington, Chesterfield (Mrs M. E. Garrod)	15*s*	Barnett Observatory, Newbold Each Friday

Name	*Secretarial Address*	*Yearly Subscription* § = members under 18, or 'juniors'	*Meeting Time and Place*
Clackmannanshire Astronomical Society	9 Deer Park, Sauchie, Alloa (J. Cluckie)	20*s*	St Mary's School, Alloa. Monthly, 3rd Friday, Sept.–May
Crawley Astronomical Society	Crawley College of Further Education, Sussex (F. D. Cooper)	7*s* 6*d*	Crawley College of Further Education Monthly
Crayford Manor House Astronomical Society	Manor House Centre, Crayford, Kent (R. H. Chambers)	None	Manor House Centre, Crayford Monthly during term-time
Dundee Astronomical Society	4 Finlaggan Place, Dundee Scotland (D. Gavine)	10*s* (§5*s*)	Mill's Observatory Dundee Fortnightly in the winter
Eastbourne Astronomical Society	80 Ringwood Road, Eastbourne, Sussex (W. O. Tutt)	21*s* (§10*s* 6*d*)	As arranged Monthly
East Lancashire Astronomical Society	95 Accrington Road, Blackburn (L. Willan)	20*s* (§7*s* 6*d*)	Longridge Observatory, Preston
Astronomical Society of Edinburgh	126 W. Saville Terrace, Edinburgh 9, Scotland (N. G. Matthew)	20*s*	Calton Hill Observatory Edinburgh Monthly
Fellowship of Junior Astronomers, Edinburgh	58 Ogilvie Terrace, Edinburgh 11, Scotland (Miss Edith McLean)	7*s* 6*d*	Calton Hill Observatory Edinburgh 2nd Sat. each month, Sept.–June
Fylde Astronomical Society	115 Abercrombie Road, Fleetwood, Lancs (P. Cuffe)	10*s*	Nautical College, Fleetwood Monthly, Sept.-May
Astronomical Society of Glasgow	164 Mugdock Road, Milngavie, Glasgow, Scotland (N. M. Orr)	10*s*	Roy. Coll. Science and Tech., Glasgow 3rd Thur. each month, Sept.–April
Leeds Astronomical Society	Maths. Dept., The University, Leeds 2 (B. L. Meek)	10*s* (§5*s*)	Leeds University Six annually
Leicester Astronomical Society	49 Bringhurst Road, Leicester (C. Shuttlewood)	21*s* (§7*s* 6*d*)	Leicester Museum and Art Gallery Monthly
Lincoln Astronomical Society	344 Brant Road, Lincoln (P. Hammerton)	20*s* (§5*s*)	Lincoln YMCA Hall 1st Tue. each month
Liverpool Astronomical Society	135 St Michael's Road, Great Crosby, Liverpool 23 (J. E. Abrahams)	15*s* (§5*s*)	Royal Institution, Liverpool Monthly
Maidenhead Astronomy Group	129 Fane Way, Maidenhead, Berkshire (S. A. H. Roper)	10*s* (§2*s* 6*d*)	Maidenhead Grammar School Once every 3 weeks
Manchester Astronomical Society	Cragside, Cliff Avenue Summerseat, Bury (Alan Whittaker)	20*s* (§10*s*)	Godlee Observatory, Manchester 1 Weekly
Newcastle-on-Tyne Astronomical Society	30 Kew Gardens, Whitley Bay, Northumberland (G. E. Manville)	20*s*	Botany Lecture Theatre, Newcastle University Monthly, Sept.–April
Nottingham Astronomical Society	18 Naseby Close, Heathfield, Nottingham (C. Swift)	25*s*	Monthly

Name	*Secretarial Address*	*Yearly Subscription* § = members under 18, or 'juniors'	*Meeting Time and Place*
Oxshott Astronomical Group	Norman Cottage, Pond Piece, Sheath Lane, Oxshott, Surrey (E. H. Noon)	10*s*	Oxshott Village Centre 1st Wed. each month Sept.–May
Plymouth Astronomical Society	5 Woodside, Lipson, Plymouth (Lawrence Harris)		(In the process of organization)
Preston and District Astronomical Society	35 Bispham Road, Carleton, Poulton-le-Fylde, Lancs (C. Lynch)	20*s* (§5*s*)	Chamber of Commerce, 49a Fishergate, Preston 3rd Mon. each month, Sept.–May
Salisbury Plain Astronomical Society	St George's Cottage Orcheston Salisbury, Wilts. (R. J. D. Nias)	10*s* (§5*s*)	St George's Rectory, Orcheston Quarterly
Sidereal Society	Flat 2, 11 Wellington Road, Brighton, Sussex (Mrs M. L. Cohen)	20*s* (§10*s*)	6 Brunswick Terrace, Hove, Sussex Each Wed., 7.30–9.30
Slough Astronomical Society	The Elms, Odds Farm, Green Common Lane, Wooburn Common, High Wycombe, Bucks (E. Shilton)	20*s*	Monthly
Southampton Astronomical Society	13 Luccombe Place, Shirley, Southampton (F. G. H. Cunningham)	20*s* (§10*s*)	*Polygon Hotel*, Southampton 2nd Thur. each month Sept.–May
Stoke-on-Trent Astronomical Society	19 Engelsea Avenue, Weston Coyney, Stoke (T. F. Stringer)	20*s*	Hanley, near Stoke-on-Trent Monthly
Swansea Astronomical Society	77 Craiglwyd Road, Cockett, Swansea (R. E. Roberts)	20*s*	As arranged
Torbay Astronomical Society	4 Heath Rise, Brixham, Devon (Miss A. Longman)	15*s* (§5*s*)	Quay Tor Hotel, Scarborough Road, Torquay Monthly
Warrington Astronomical Society	2 Dale Avenue, Appleton, Warrington (B. P. Rees)	20*s*	Central Library, Museum Street, Warrington, Lancs Monthly. Sept.–May
Warwickshire Astronomical Society	20 Humber Road, Coventry, Warwickshire (R. D. Wood)	80*s*	20 Humber Road, Coventry Each Tuesday
Wolverhampton Astronomical Society	Garwick, 8 Holme Mill, Fordhouses, Wolverhampton (M. Astley)	20*s*	38 Tettenhall Road, Wolverhampton Alternate Mon., Sept.–April
Wyvern Astronomical Society	2 Howcroft, Churchdown Gloucester, (A. F. Edwards)	15*s* (§5*s*)	Clubhouse, Churcham Last Frid. of each month except Aug.
York Astronomical Society	97 Carr Lane, Acomb, York (R. Emmerson)	20*s* (§5*s*)	As arranged Monthly, Sept.–May

It is possible that this list of local societies may not be quite complete. If any have been omitted, the secretaries concerned are invited to write to the Editor (c/o Messrs. Eyre & Spottiswoode (Publishers), Ltd, 167 Fleet Street, London EC4), so that the relevant notes may be included in the 1968 *Yearbook*.

Some Recent Books

Lunar Geology, by Gilbert Fielder. (Lutterworth Press, 1964.) A semi-technical account of modern lunar research, approached from the geological viewpoint and containing much original work by the author.

Naked-Eye Astronomy, by Patrick Moore. (Lutterworth Press, 1966.) An account of what may be seen in the sky by the beginner who has no telescopic equipment whatsoever.

1001 Questions Answered About Astronomy, by J. S. Pickering. (Lutterworth Press, 1965.) A general survey for beginners, in question-and-answer form, by a well-known American writer. This is a revision of the book which first appeared some years ago.

Mars, by R. S. Richardson. (Allen and Unwin, 1965.) An account of what is known about Mars, illustrated by magnificent colour paintings by Chesley Bonestell.

The Origin and Evolution of the Universe, by E. Schatzman. (Hutchinson, 1966.) Semi-technical, but clearly written and immensely informative.

The Mystery of the Expanding Universe, by William Bonnor (Eyre & Spottiswoode, 1965). Very clear summary of modern cosmological theories.

Worlds Apart, by N. J. Berrill (Sidgwick & Jackson, 1966). An introduction to 'exobiology' – the science of the possibility of life beyond the Earth.

Map of the Moon, by Patrick Moore. Diameter 25 inches, published privately.

Yearbook of Astronomy 1967

Editor Patrick Moore

This Yearbook has been specially designed for the amateur astronomer and, once again, the new edition has been completely revised. The notes and data for 1967 have been entirely rewritten and a new series of articles included.

We have kept to our policy of presenting articles of a wide range of subjects, but this year we have also included a more technical review article—by Dr. E. M. Lindsay on Quasars—which will be of value to those readers who would like more information on one of the fundamental problems of modern astronomy. Other articles in the Yearbook deal with Sundials, the Isaac Newton Telescope, the Craters on Mars, Image Convertors in astronomy, and the Van Allen Belts, as well as Patrick Moore's Recent Advances in Astronomy. There are also details of coloured stars and a Cycle of Variable Stars suitable for the amateur telescopic observer, which is included for the first time in this edition. A full list of societies that the amateur astronomer can join is also given.

The Yearbook is of great value to all interested in astronomy and particularly to the amateur who likes to look out for astronomical events.

The illustration on the front of the jacket is of the Isaac Newton Telescope, under construction by Messrs. Grubb Parsons and is reproduced with their kind permission.

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